Short-Term Changes in Positive Affective Experiences and their Relation to Interindividual Differences in Subjective Well-Being: A Multimethod Approach

Dissertation
zur Erlangung des akademischen Grades
Doctor rerum naturalium (Dr. rer. nat.)
im Fach Psychologie

eingereicht an der
Lebenswissenschaftlichen Fakultät
der Humboldt-Universität zu Berlin

vorgelegt von
M.Sc. Johanna Marie Große Rüschkamp

Berlin, 2019

Präsidentin der Humboldt-Universität zu Berlin:
Prof. Dr.-Ing. Dr. Sabine Kunst

Dekan der Lebenswissenschaftlichen Fakultät der Humboldt-Universität zu Berlin:
Prof. Dr. Bernhard Grimm

Gutachter:
1. Dr. Annette Brose, Humboldt-Universität zu Berlin
2. Prof. Dr. Arno Villringer, Max Planck Institut für Kognitions-und Neurowissenschaften Leipzig
3. Prof. Dr. Lutz Jäncke, University of Zurich

Tag der mündlichen Prüfung: 03.07.2019

Eidesstattliche Erklärung

Hiermit erkläre ich an Eides statt, dass ich die vorliegende Dissertation selbstständig und ohne unerlaubte Hilfe verfasst habe. Die verwendete Literatur und anderweitig verwendete Hilfsmittel sind kenntlich gemacht und vollständig angegeben. Ich habe mich mit dieser Arbeit nicht bereits anderwärts um einen Doktorgrad beworben und ich besitze auch keinen Doktorgrad in dem Promotionsfach Psychologie. Die zugrundeliegende Promotionsordnung vom 05. März 2015 ist mir bekannt.

Berlin, den 04.04.2019

Johanna Marie Grosse Rueschkamp

Acknowledgements

My deepest gratitude goes to my supervisor Dr. Annette Brose, who showed me her full support throughout the four years of my work on this dissertation. Her valuable insights, helpful advice, and endless feedback at every stage of this dissertation have taught me a tremendous amount about being a scientist. Thank you for taking me on as your PhD student.

I am also very grateful to my second supervisor Dr. Michael Gaebler. Thank you for starting the POSEMO project with me – it has always been a dream of mine to conduct my own neuroimaging study. You taught me the art of neuroimaging, Matlab coding, and SPM analyses – yet, most of all I appreciated your positive attitude and encouragement, which really motivated me and has helped me keep a positive outlook on my work.

Further, I would like to thank Prof. Dr. Arno Villringer for his support of my POSEMO project, for providing his scientific perspective, and, most of all, for giving me the opportunity to be part of his great research group at the MindBrainBody Institute. I am very happy to have met every single one of the amazing Real Fingers.

A big thank you also goes to Elli for being the best office buddy. Thank you for your advice, your helpful feedback, and the countless discussions (work-related and otherwise), for answering my (smarter and less smart) questions and for your emotional support. I will for sure miss our coffee breaks and KitKat-trips to the first floor-vending machine.

I am very grateful to have been part of the International Max Planck Research School on the Life Course (LIFE). Besides supporting my doctoral studies financially, LIFE has provided a highly intellectually stimulating environment with many opportunities to exchange ideas, to engage in fruitful discussions and to learn from great scientists. Yet, the greatest part of LIFE has been the other fellows, who not only made every single academy and seminar great fun, but who have also become good friends beyond.

Special thanks also goes to a number of other people. First of all to Kai, for some emergency R-coding, for proof-reading this dissertation, for many coffee breaks and for making Adlershof a lot more fun. Thanks to Stefan for having been part of our small research group, for always helping out and for our conversations about life. And a big thank you also goes to Jennifer and Sandy who have

spent many hours at the scanner with me and have been a great help with data collection for the POSEMO study.

Finally, the biggest thank you goes to my family, especially my parents. I could not have done this without the unconditional support you have given me throughout my whole life. Thank you also to my brother Benjamin and my sister Sophie for always being there for me. And thank you to my godmother Dorothee for the encouragement and uplifts.

Abstract

Levels of subjective well-being differ across individuals, that is, some people are happier than others. Within the study of subjective well-being, research aims to uncover the psychological and physiological processes underlying subjective well-being and interindividual differences therein. The work in this dissertation aims to contribute to this. It focused on positive emotionality as a constituent element of subjective well-being and the idea that the maximization of positive experiences is one of the processes underlying higher levels of subjective well-being. More specifically, this dissertation investigates the affective processes – affective reactivity and emotion regulation – underlying short-term changes in positive affective experiences and their relation to interindividual differences in subjective well-being. The three main research objectives that were addressed in the empirical studies of this dissertation concerned (1) whether stronger increases in positive affect when reacting to and when up-regulating in response to positive stimuli in the laboratory relate to higher subjective well-being, (2) which brain regions underlie changes in positive affective experiences, particularly during the up-regulation of positive emotions, and (3) whether enhanced or reduced affective reactivity to positive events in daily life relates to higher subjective well-being. Together, the studies thus encompass investigations of affective reactivity and emotion regulation at two levels of analysis (the subjective and neural level) as well as across multiple methods (in the laboratory and in daily life).

Overall, findings showed that greater increases in positive affect (through enhanced affective reactivity to positive events or through greater success in up-regulating positive emotions) were not related to higher subjective well-being, both when investigated in the laboratory and in daily life. Instead, people with higher levels of subjective well-being showed reduced affective reactions to positive events in daily life, pointing to the importance of a relative greater emotional stability for higher subjective well-being. At the neural level, changes in positive affective experiences were mirrored by increased activations in emotion-related (medial frontal and subcortical) regions as well as deactivation in a fronto-parietal control network. The ventral striatum (VS) in particular related to changes in positive affect during the up-regulation of positive emotions in the laboratory, however, not to changes in affect when up-regulating in daily life.

Together, the work in this dissertation indicates that not the experience of particularly intense positive affective states, but rather less fluctuation in momentary positive affective experiences seems to be essential to the overall composition of subjective well-being. The present dissertation thus points to the importance of considering dynamic aspects of positive emotionality for gaining a better understanding of subjective well-being and specifically higher subjective well-being. Given that findings in this dissertation were informed by investigations from both the laboratory and daily life, the present dissertation further emphasizes the need to integrate different methods in the study of emotion. Concluding, this dissertation advances our understanding of the processes underlying subjective well-being and, therefore, adds to our understanding of differences in people's happiness.

Zusammenfassung

Personen unterscheiden sich in dem, wie sie sich im Allgemeinen fühlen, kurz gesagt, manche Menschen sind glücklicher als andere. Das Ziel der Forschung zu subjektivem Wohlbefinden ist es, die psychologischen und physiologischen Prozesse, die diesen Personenunterschieden zugrunde liegen, zu beschreiben und zu verstehen. Das Anliegen dieser Dissertation ist es hierzu einen Beitrag zu leisten. Der spezifische Forschungsschwerpunkt lag auf affektivem positivem Erleben, als einem wichtigen Bestandteil von subjektivem Wohlbefinden, und der Annahme, dass Personen mit besonders hohem subjektivem Wohlbefinden ihr positives Erleben verstärken und so maximal davon profitieren. In dieser Dissertation wurden insbesondere die affektiven Prozesse – affektive Reaktivität und Emotionsregulation – welche den kurzfristigen Veränderungen positiver affektiver Erfahrungen zugrunde liegen, untersucht und mit Personenunterschieden in subjektivem Wohlbefinden verbunden. In drei empirischen Studien wurden die folgenden Forschungsfragen untersucht: (1) Haben Personen mit höherem subjektiven Wohlbefinden einen stärkeren Anstieg in positivem Affekt, wenn sie auf positive Stimuli im Labor reagieren oder ihre positiven Emotionen hochregulieren? (2) Welches sind die neuronalen Korrelate, die diesen kurzfristigen Veränderungen in positivem Affekt zugrunde liegen, insbesondere während der Hochregulation positiver Emotionen? Und (3) hängt ein höheres subjektives Wohlbefinden mit einer stärkeren oder geringeren Reaktion auf positive Ereignisse im Alltag zusammen? Diese empirischen Studien umfassen Untersuchungen der affektiven Reaktivität und der Emotionsregulation auf zwei Analyseebenen (subjektive und neuronale Ebene), sowie Untersuchungen im Labor und im täglichen Leben.

Das Gesamtbild der empirischen Befunde hat gezeigt, dass ein stärkerer Anstieg in positivem Affekt (durch eine stärkere Reaktion auf positive Ereignisse oder durch das bewusste Hochregulieren positiver Emotionen) nicht mit einem höheren subjektiven Wohlbefinden zusammenhängt. Stattdessen hatten Personen mit einem höheren subjektiven Wohlbefinden eine geringere Reaktivität auf positive Ereignisse im Alltag, was auf die Wichtigkeit von emotionaler Stabilität (geringere Schwankungen in positivem Affekt) für hohes Wohlbefinden hindeutet. Auf der neuronalen Ebene spiegelten sich die Veränderungen in positivem Affekt durch eine durch verstärkte neuronale Aktivierung in emotionsbezogenen (medialen frontalen und subkortikalen) Regionen wieder, sowie durch eine

Deaktivierung in einem fronto-parietalen Kontrollnetzwerk. Eine verstärkte Aktivierung des ventralen Striatums (VS) hing insbesondere mit einem verstärkten Anstieg in positivem Affekt während der Hochregulation positiver Emotionen im Labor zusammen, nicht jedoch mit der Veränderung in Affekt während der Regulation im Alltag.

Die Arbeit dieser Dissertation zeigt, dass nicht besonders intensives positives Erleben, sondern eher weniger Schwankungen in momentanen positiven affektiven Zuständen wichtig für das allgemeine Wohlbefinden sind. Die vorliegende Dissertation unterstreicht daher, dass, für ein besseres Verständnis von subjektivem Wohlbefinden, es wichtig ist auch kurzfristige Dynamiken des affektiven Erlebens zu berücksichtigen. Darüber hinaus zeigt diese Dissertation die Wichtigkeit auf verschiedene Analyseebenen und Untersuchungsmethoden (z. B. Datenerfassungen im Labor und im Alltag) in die Erforschung von affektivem Erleben und subjektivem Wohlbefinden zu integrieren. Insgesamt liefert diese Dissertation einen Beitrag zu unserem Verständnis der Prozesse die dem subjektiven Wohlbefinden zugrunde liegen.

List of Papers Contributing to this Dissertation

Paper I

Grosse Rueschkamp, J. M., Blanke, E. S., & Brose, A. (2019). *Two sides of the same coin? Only self-reported, but not performance-based regulation of positive emotions relates to subjective well-being*. Manuscript under review for *The Journal of Positive Psychology*.

Paper II

Grosse Rueschkamp, J. M., Brose, A., Villringer, A., & Gaebler, M. (2019). *Neural correlates of up-regulating positive emotions in fMRI and their link to affect in daily life*. Manuscript in revision for *Social Cognitive and Affective Neuroscience*.

Paper III

Grosse Rueschkamp, J. M., Kuppens, P., Riediger, M., Blanke, E., & Brose, A. (2018). Higher well-being is related to reduced affective reactivity to positive events in daily life. *Emotion*. http://doi.org/10.1037/emo0000557

Contents

1 Introduction 11
2 Essential Concepts and Overview 14
2.1 Subjective Well-Being 14
2.2 Positive Affective Experiences and Subjective Well-Being 16
2.3 Affect Dynamics and Subjective Well-Being 18
2.4 Short-Term Affective Processes and the Development of Subjective Well-Being 21
3 Overarching Aim 22
4 Affective Reactivity and Emotion Regulation 25
4.1 Affective Reactivity to Positive Events 26
4.1.1 Subjective Experience 26
4.1.2 Link to Subjective Well-Being 27
4.1.3 Neural Level 28
4.2 Up-Regulation of Positive Emotions 30
4.2.1 Subjective Experience 30
4.2.2 Link to Subjective Well-Being 32
4.2.3 Neural Level 32
5 Affective Reactivity and Emotion Regulation: A Multimethod Approach 34
6 Summary of Aims and Research Objectives 36
7 Paper I 40
8 Paper II 56
9 Paper III 87
10 General Discussion 118
10.1 Affective Reactivity, Emotion Regulation and Subjective Well-Being 120
10.2 Neural Responses Underlying Changes in Positive Affective Experiences 123
10.3 Positive Affect Dynamics: Making the Most of the Least 125
10.4 Long-Term Dynamics of Positive Affective Experiences and Subjective Well-Being 126
10.5 Assessing Affective Reactivity, Emotion Regulation and Subjective Well-Being 129
11 Limitations 136
12 Future Research Directions 138
13 Conclusion 143
14 References 145

1 Introduction

Humans have a strong quest for happiness. Already articulated by ancient Greek philosophers, Aristotle for example wrote that "happiness is the meaning and the purpose of life, the whole aim and end of human existence" (Aristotle, *Nichomachean Ethics*). Modern scientists have supported this claim by showing that across different cultures, most people find the pursuit of happiness to be an important goal in life (Diener, 2000). Yet, there are substantial differences among people in how happy they are. Some people seem to generally possess positive conceptions about their life (Taylor & Brown, 1988), while others seem to derive little joy from it (Myers & Diener, 1995). Hence, the question arises: *Why are some people happier than others?*

Scientifically, this question can be approached through the study of well-being. Two different perspectives have emerged in an attempt to specifically study positive aspects of well-being, that is, positive human health and flourishing. According to one view, well-being is about the maximization of pleasure and avoidance of displeasure (hedonic well-being; Diener, Suh, Lucas, & Smith, 1999), while the other emphasizes personal growth and self-realization (eudaimonic well-being; Ryan & Deci, 2001). The former – most often associated with the common meaning of happiness – is at the focus of the present dissertation. The hedonic view of well-being has been strongly influenced by the work of Diener (1984) who introduced the concept of *subjective well-being*, reflecting the subjective evaluation of one's life in terms of the experiences and cognitive judgments. Research on subjective well-being has the goal to understand and explain the complex psychological and physiological processes underlying differences in subjective well-being and to identify factors that promote higher levels of subjective well-being (Diener et al., 1999; Lyubomirsky, 2001; Seligman & Csikszentmihalyi, 2000). The work of this dissertation can be understood along these lines. It focuses on positive affective experiences[1] and their role in subjective well-being, and higher subjective well-

[1] *Affect* is usually used as an umbrella term for positively or negatively valenced psychological states, which encompasses both the experience of discrete *emotions* (e.g., joy or pride) as well as *moods*, which in contrast to the former, are longer-lasting and do not have an apparent trigger (Gross & Thompson, 2007). Yet, in accordance with the broad literature that does not distinguish between affect and emotion (e.g., Kuppens, 2015), these two terms are used interchangeably in the present dissertation.

being in particular. The idea that positive emotions are essential to subjective well-being seems very intuitive. Experiencing frequent and intense moments of feelings such as joy, love, or contentment should make one feel generally happier in life. This presumption is supported by theories that suggest a pivotal role of intense positive experiences in higher subjective well-being and stress the benefits of positive emotions for psychological functioning (Bryant, 2003; Bryant & Veroff, 2007; Fredrickson, 2001). In line with this, studies found high levels of positive emotions to be linked to – and also precede – various successful outcomes across multiple life domains, such job performance or marital happiness (Lyubomirsky, King, & Diener, 2005).

Most empirical approaches to the study of positive emotions as a constituent element of subjective well-being have focused on trait levels of positive emotions, that is, stable levels of positive affect that differ reliably across people (Costa & McCrae, 1980). One person may generally be described as happy, whereas another may be unhappy most of the time. Yet, emotions are dynamic in their nature, that is, they differ not only between people, but also fluctuate within individuals over time. Studying this within-person or intraindividual variability is of value as it informs on the underlying affective processes, namely *affective reactivity* in responses to (changing) environmental demands, and *emotion regulation* (Kuppens, Oravecz, & Tuerlinckx, 2010). These affective processes are not only thought to be an important aspect of one's daily affective functioning (Ong, Sin, & Ram, 2018; Röcke & Brose, 2013; Wessman & Ricks, 1966), but have also been theorized to be key mechanisms in the development of well-being and interindividual differences therein (Hollenstein, Lichtwarck-Aschoff, & Potworowski, 2013). Therefore, to better understand the role of positive affective experiences in subjective well-being, it is essential to not just consider stable levels of positive emotions, but to also take dynamic aspects into account.

The present dissertation investigates the affective processes underlying short-term changes in positive affective experiences, as they occur within individuals, and relates these to between-person, that is, interindividual differences in subjective well-being. I specifically test whether enhanced or reduced affective reactivity to positive events relates to higher subjective well-being and whether greater increases in positive affect, when up-regulating positive emotions, relate to higher subjective well-being. Both subjective and neurophysiologcial aspects of affective reactivity and emotion

regulation are considered. To better understand both the basic mechanisms of the affective processes and how they unfold in everyday life, both laboratory and daily life research designs are used across and within studies. Specific research objectives are addressed in three empirical studies.

First, I sought to relate affective reactivity and the up-regulation of positive emotions, as measured in the laboratory, to interindividual differences in subjective well-being (*Paper I)*. Previous studies established a relation between, for example, greater trait levels of positive emotion regulation and higher levels of subjective well-being (e.g., Bryant, 2003). The research objective was thus to assess affective reactivity and the up-regulation of positive emotions through repeated reports of participants' momentary affective experiences (capturing actual within-person changes in affective experiences) and to relate these performance-based indicators of affective reactivity and emotion regulation to subjective well-being.

Following up on the previous, I examined the neural responses associated with within-person changes in positive affective experiences (*Paper II*), particularly during the up-regulation of positive emotions. The research objective was to elucidate the functional role of the ventral striatum – previously associated with differences in affect across people when up-regulating positive emotions (e.g., Greening, Osuch, Williamson, & Mitchell, 2014) – and to test whether increased activation in the ventral striatum also relates to within-person changes in affect (i.e., trial-to-trial changes). Further, I examined whether increased activation in the ventral striatum during up-regulation in the laboratory, relates to greater changes in affect when up-regulating positive emotions in daily life.

Last, I investigated the relation between interindividual differences in subjective well-being and affective reactivity to positive events as measured in daily life (Grosse Rueschkamp, Kuppens, Riediger, Blanke, & Brose, 2018). Earlier research on affective reactivity only yielded an inconsistent picture. While some studies speak in favor of enhanced affective reactivity to positive events in people with higher subjective well-being (e.g., Bylsma, Morris, & Rottenberg, 2008; Carl, Fairholme, Gallagher, Thompson-Hollands, & Barlow, 2014), in line with the idea that intense positive emotions are beneficial for subjective well-being (Fredrickson, 2001), other theoretical assumptions and empirical findings point in the opposite direction (e.g., Oishi, Diener, Choi, Kim-Prieto, & Choi, 2007; Solomon, 1980). Thus, the research objective was to systematically test whether individuals with

higher levels of subjective well-being have enhanced or reduced affective reactivity to positive events in daily life.

In the following, I will give an overview of essential concepts and describe a conceptual framework, which allows for the inclusion of both stable and dynamic aspects in the study of positive affective experiences and subjective well-being. Subsequently, I will give a detailed description of affective reactivity and emotion regulation at the subjective and the neural level, as well as an outline of how the multimethod approach of this dissertation is motivated. Finally, I will summarize the aim and specific research objectives of this dissertation.

2 Essential Concepts and Overview

2.1 Subjective Well-Being

Subjective well-being is an integral element of human flourishing, that is, optimal human functioning (Keyes, 2002). It does not merely represent the absence of mental illness and psychopathology, but rather relates to a second dimension that characterizes the presence of mental health (Keyes, 2002; Ryff & Keyes, 1995). In line with this, the World Health Organization (2014) stated that "health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (p.1), acknowledging that the absence of mental illness is a necessary, but not sufficient, condition for the presence of human flourishing.

Subjective well-being is most commonly defined in terms of three components: The experience of high levels of positive and low levels of negative affect (affective components), and high life satisfaction (the cognitive component; Diener et al., 1999). As such, subjective well-being is considered a stable characteristic that differs between individuals (i.e., a trait; Costa & McCrae, 1980), indicating how people feel and think about their lives in general. According to this definition, a happy person would be someone who experiences predominantly pleasant emotions, only few unpleasant emotions, and who generally evaluates his or her life as positive. In line with the idea that subjective well-being is associated with a variety of desirable characteristics and favorable life circumstances (Diener et al., 1999), high trait levels of positive affect have been linked to a reduced susceptibility to

cardiovascular disease (Harker & Keltner, 2001), greater marital satisfaction (Boehm & Kubzansky, 2012) and a longer life (Danner, Snowdon, & Friesen, 2001). A meta-analysis comprising more than three hundred studies found that high trait levels of positive affect are not only linked to, but also precede various successful outcomes and behaviors across multiple life domains, such as marriage, friendship, work performance, income, and health (Lyubomirsky et al., 2005).

A key assertion of Diener's (1999) conception of subjective well-being is that positive and negative affect are two distinct components. Indeed, in line with the finding that positive and negative affect are only mildly (negatively) correlated (e.g., Bradburn, 1969), one prominent view proposes that positive and negative affect are two orthogonal bipolar dimensions (Tellegen, Watson, & Clark, 1999; Watson & Tellegen, 1985). This assumption of independence of positive and negative affect has been supported by different lines of research. For example, Cacioppo and colleagues (1999; 1997) suggest that two distinct affect systems (components of the nervous system) facilitate approach and avoidance behavior, respectively, and that positive and negative affect are therefore processed separately. Accordingly, studies from the affective neurosciences have associated different affective states with distinct neural circuitries. While approach-motivated affective states have been shown to primarily relate to activation in medial prefrontal cortex and specifically the striatum, avoidance-motivated affective states were systematically related to the amygdala and the anterior cingulate cortex (Wager, Phan, Liberzon, & Taylor, 2003). Finally, research from personality psychology is also informative on the interrelation between positive and negative affect. In particular, the two personality dimensions of extraversion and neuroticism are thought to predispose individuals to the experience of positive and negative affect, respectively (Eysenck & Eysenck, 1987), an assumption that has been demonstrated across numerous studies (e.g., Costa & McCrae, 1980; Larsen & Ketelaar, 1991; Rusting & Larsen, 1997). Together, the associations of positive and negative affect with distinct physiological and psychological measures (e.g., neural activations, personality traits) further support the argument for conceptualizing positive and negative affect as independent dimensions. With regard to subjective well-being, this implies that alleviating distress and negative affect does not (necessarily) indicate the

experience of high levels of positive affect. Therefore, understanding the processes that promote positive affective experiences constitutes an important inquiry in research on subjective well-being.

2.2 Positive Affective Experiences and Subjective Well-Being

Theoretical work from the realm of positive psychology has aimed at elucidating the psychological processes by which momentary positive affective experiences may promote high levels of positive affect, that is, higher subjective well-being. One theory is the "broaden-and-build theory" by Fredrickson (2001), which suggests that positive affective experiences trigger an upward-spiral of positive emotions that leads to higher subjective well-being. More precisely, the experience of positive emotions is thought to broaden people's attention, thinking, and behavioral tendencies in ways that enable them to build a host of personal resources – cognitive, psychological, social, and physical. This improved mental and physical functioning then leads to greater openness towards future experiences of positive emotions. For example, experiencing excitement motivates engaging in activities and social encounters, which in turn increases further experiences of positive emotions. In other words, positive emotions and broadened thinking and behavior enhance each other. The broaden-and-build theory not only stresses the adaptive short-term effects of positive affective experiences on daily functioning (i.e., broadening of cognition and attention) but also suggests that they, over time, turn into more durable benefits (i.e., the building of personal resources) which increase subjective well-being.

Empirical research has supported some of the basic assumptions of the broaden-and-build theory. For instance, the induction of positive emotions was related to a broader attentional scope (measured in a global-local visual processing task) and to higher action tendencies (measured via an open-ended Twenty Statements test; Fredrickson & Branigan, 2005), compared to a neutral control condition. Another study demonstrated that positive affect and broadened thinking, as measured with self-report questionnaires, reciprocally enhanced each other over a time period of five weeks (Fredrickson & Joiner, 2002). However, it is important to note that the broadening effect may not be the same for different positive emotions. According to Gable and Harmon-Jones (2008), positive affective states differ in the degree to which they facilitate the motivation to approach. The authors showed that only emotions scoring low on approach motivation (e.g., joy) broaden one's attention and

thinking, while emotions with higher approach-motivation scores (e.g., interest) are associated with rather narrowed cognition and attention – the latter presumably facilitating the pursuit of one's personal goals.

While the broaden-and-build theory stresses the general adaptive function of positive emotions, another theoretical account, the savoring account, describes the process through which people derive joy from the positive affective experiences in their lives – and how this process is related to interindividual differences in subjective well-being. According to Bryant and colleagues (2003; 2007) some people are more attuned to their positive emotions, appreciative of the positive moments in their life, and therefore enjoy these moments more and for a longer period of time (Bryant, 2003; Bryant & Veroff, 2007). These people have a tendency to maximize their positive experiences, that is, they savor positive experiences more than others. This process of savoring is proposed to be one of the mechanisms underlying particular high levels of subjective well-being.

Empirical evidence speaks in favor of these theoretical claims made by the savoring account. One study showed that savoring positive experiences is related to increased levels of momentary happiness (Jose, Lim, & Bryant, 2012). Additionally, Bryant (2003) showed that people who had stronger beliefs in their capacity to savor positive experiences were also the ones with higher levels of self-reported well-being. Similarly, high levels of trait savoring were predictive of greater global happiness scores, higher life satisfaction, as well as lower levels of depressive symptoms in a sample of older adults (Smith & Hollinger-Smith, 2015). Importantly, the savoring account also seems to be compatible with the broaden-and-build theory outlined above. It would be possible, for example, that actively savoring one's positive emotions broadens one's cognitive and attentional repertoire. In sum, these theoretical notions suggest that the promotion of intense positive affective experiences over time may lead to increased subjective well-being.

By outlining the psychological processes by which positive affective experiences may contribute to overall high levels of positive affect, both theories, as reviewed above, are concerned with *affective states*, that is, momentary affective experiences as they occur *within* individuals over time. Empirically, however, these theories have mainly been approached through single-occasion

study designs, which capture *trait levels* of affect or *interindividual differences* in affective experience. Yet, for a comprehensive understanding of psychological phenomena that manifest significant moment-to-moment change (e.g., affective experiences), within-person variability must be considered (Nesselroade, 1991, 2001). Moreover, as the psychological processes, as theoretically outlined by the broaden-and-build theory and the savoring account, are dynamic in their nature (i.e., they unfold across time); single trait measures or interindividual difference measures do not suffice to capture them.

Finally, single-occasion study designs usually makes use of retrospective self-reports, that require people to average across various contexts and to make rather global evaluations of their affective experiences. For example, people are asked to estimate how intense they experience positive or negative emotions "in general" or in reference to a certain period of time (e.g., the past two weeks). The underlying assumption is that these measures reflect an accumulation of the variety of affective states a person experiences over time. However, assessments of momentary affective experiences differ from retrospective self-reports (e.g., trait measures) of emotion in important ways: Retrospective self-reports rely on memory about past emotional events (i.e., episodic memory) or more general beliefs about oneself (i.e., semantic knowledge; Robinson & Clore, 2002a, 2002b). Thus, these reports are likely to be influenced by memory-specific or belief-based biases, such as identity-related or cultural beliefs about emotion. For example, a person with a positive self-belief will likely rate his overall emotional state as more positive, compared to a person with a less positive concept of herself. In contrast, online reports, that capture actual affective experiences in the moment, draw upon experiential knowledge and are therefore less prone to the biases as just described (Robinson & Clore, 2002a, 2002b). Together, to provide some indication of how positive affective experiences unfold within individuals, it is imperative to take a process-oriented approach, in which affective states are captured repeatedly over time (Ong, Horn, & Walsh, 2007; Rush, Ong, Hofer, & Horn, 2017).

2.3 Affect Dynamics and Subjective Well-Being

As suggested above, one inherent characteristic of affective experiences is that they change from moment to moment, that is, people are not happy all the time, but there are more and less happy

moments. Descriptive reports of these short-term changes show, for example, that within-person variability of daily positive and negative affect (measured over 45 days) comprises more than half of the size of the variability of affect observed between individuals (Röcke, Li, & Smith, 2009). Within-person variability has also been shown to be more pronounced in positive than in negative affective states (Eid & Diener, 1999). Importantly, the degree to which emotions change from moment to moment also differs between people (Kuppens, Stouten, & Mesquita, 2009). Studies in the field of personality psychology have shown that people high in neuroticism not only have a predisposition to high *mean* levels of negative affect but also greater *variability* in negative affect (Eid & Diener, 1999; McConville & Cooper, 1998; Williams, 1990), possibly due to a greater sensitivity to negative stimuli and situations (Eysenck & Eysenck, 1987). Age-differences in affect variability have also been documented, with greater variability in younger than in older adults (Röcke et al., 2009). Finally, Eid and Diener (1999) demonstrated that interindividual differences in daily fluctuations of emotions are considerably stable over time, leading them to consider affect variability a characteristic of people's personality.

Short-term changes in affect have also been related to interindividual differences in stable levels of emotion and well-being. In a recent meta-analysis, it has been shown that relatively much stability in emotions (i.e., comparatively little fluctuation between successive measurement occasions), lower emotional variability (i.e., deviation of affective states from mean levels of emotion), and lower emotional inertia (i.e., how much an affective state carries over from one moment to the next) are related to both higher levels of subjective well-being and lower levels of psychopathology (Houben, Van Den Noortgate, & Kuppens, 2015). Although most of the studies included in this meta-analysis focused on negative emotions, positive emotion dynamics have also been linked to well-being: A lower variability in positive emotions has been related to a greater life satisfaction and happiness (i.e., greater subjective well-being), as well as to lower levels of depressive and anxiety symptoms – even after controlling for overall levels of positive emotions (Gruber, Kogan, Quoidbach, & Mauss, 2013). In summary, to which extent our emotions change is an important aspect of our emotional lives (Eid & Diener, 1999; Röcke & Brose, 2013; Wessman & Ricks, 1966). Thus, for a comprehensive

understanding of subjective well-being and interindividual differences therein it is (1) essential to move beyond stable levels of (high or low) positive affect and to systematically consider dynamic aspects and (2) crucial to delineate the psychological and physiological processes that underlie short-term changes in positive affective experiences. These psychological and physiological processes that shape people's affective experiences in specific situations should offer explanation for how short-term variation in affective experiences come about and therefore also possibly provide a unique window through which interindividual differences in more stable emotion outcomes, such as well-being, can be understood.

Moment-to-moment changes in our affective experiences are thought to be governed by the way we respond to emotionally relevant events and how we regulate our emotions (Hoeksma, Oosterlaan, & Schipper, 2004; Kuppens et al., 2010). Though often related and even intertwined (Gross & Barrett, 2011), these changes mark different underlying affective processes, two of which are affective reactivity and emotion regulation (but see for example Kuppens & Verduyn, 2017 for the inclusion of inertia and interaction as affective processes). *Affective reactivity* represents the spontaneous reaction to an internal or external event, based on its appraisal as rewarding or threatening (Lazarus, 1991). *Emotion regulation* refers to the effortful attempts to change or otherwise modulate (e.g., inhibit or initiate) the spontaneous affective reaction, resulting in changes in the temporal features of the affective experience (e.g., duration and intensity; Gross, 1998; Kuppens et al., 2010). In accordance with the conceptualization of emotions as multicomponent phenomena, these affective processes are thought to shape affective experiences, together with loosely coupled changes in behavior and physiology (Mauss, Levenson, McCarter, Wilhelm, & Gross, 2005). Importantly, there are substantial differences across people in the strength of their affective reactions and their regulatory capacities (Kuppens et al., 2010). For example, some people might experience more positive affect in positive situations than others, or alternatively, some people might be more successful in enhancing positive affective experiences through deliberate regulation attempts.

2.4 Short-Term Affective Processes and the Development of Subjective Well-Being

Different theories propose that people's daily changing affective experiences and behaviors are key mechanisms in the development of well-being and interindividual differences therein. For example, it has been proposed that daily experiences and one's responses to these accumulate and may predispose people to the development of mental disorders, such as depression (Wichers, 2014). Some people might experience more negative affect in negative or stressful situations or they may take longer before turning to their baseline level of affect (Kramer et al., 2014). These heightened negative experiences in daily life, resulting from affective dysfunctional affective processing (e.g., enhanced affective reactions or emotion dysregulation) are thought to cumulatively lead to negative long-term outcomes and higher levels of depressive symptoms in particular (Wichers, 2014). Thus, in this view, depression is not seen as a discrete diagnostic entity, but rather reflects a dynamic process that plays out in everyday life.

Such dynamic perspective on the emergence of interindividual differences in long-term emotional outcomes has also been adapted by another theoretical framework of flexibility and affective change. More specifically, it has been proposed that flexibility in affective experiences and behaviors occurs at three different time scales (Hollenstein et al., 2013): At the micro level, flexibility reflects affective change that is observable within a specific context, at the meso level, flexibility is assessed as affective changes in response to changing contextual demands. Finally, at the macro level, flexibility refers to more enduring affective change, which reflects transitions as a result from adaptation to life events or developmental change. Importantly, through continuing interactions between these levels, changes at lower levels (e.g., affective reactions to daily events) may give rise to more enduring changes at higher levels (e.g., increases or decreases in levels of well-being), and simultaneously, these higher-level changes constrain changes at lower levels (e.g., one's level of well-being determines how one reacts to daily events). In short, this suggests that interindividual differences in well-being evolve over time and reside in the affect dynamics of everyday life.

The idea of approaching stable person characteristics (e.g., well-being) not merely as a trait, but rather as a process that evolves over time, has been prominent in personality research, and research

on the personality trait of neuroticism and daily stress processes, in particular. For example, Suls and Martin (2005) reviewed studies that all used longitudinal designs to investigate the impact of negative affect dynamics on neuroticism. They showed that more frequent experiences of stressful events, stronger negative appraisals, enhanced affective reactions to these events, and greater inertia of negative affect all contributed to the experience of high levels of negative affect and high neuroticism. While studies on the prospective link between positive affect dynamics and stable person characteristics is scarce, one recent study showed that daily positive affective experiences may elicit change in personality traits (Borghuis et al., 2018). In this study, higher daily positive affect predicted changes in Big-Five personality traits (i.e., increases in extraversion, agreeableness, conscientiousness, emotional stability and openness) over a five-year time period (Borghuis et al., 2018).

Research has also examined the prospective links of short-term affective processes on the development of well-being. In one study, a heightened reactivity to negative events in daily life was related to increased levels of depressive symptoms about 10 years later (Charles, Piazza, Mogle, Sliwinski, & Almeida, 2013). In another study, the experience of negative events in daily life (i.e., perceived intensity of negative events and the affective reactivity to those events) was predictive of depressive symptoms across three waves of experience sampling over a period of one year (Brose, Wichers, & Kuppens, 2017). Moreover, enhanced levels of ruminative thinking in response to negative experiences, thought to reflect maladaptive emotion regulation, have been shown to predict heightened levels of depressive symptoms up to 15 months later (Vanderhasselt, Brose, Koster, & De Raedt, 2016). Taken together, these theoretical notions and empirical evidence stress the importance of investigating the affective processes underlying changing affective experiences in daily life when aiming to understand well-being.

3 Overarching Aim

The overarching aim of this dissertation is to better understand interindividual differences in subjective well-being and specifically higher subjective well-being. So far, I have presented two different lines of work that take different stances on understanding the development of subjective well-

being. The first – originating in the study of positive psychology – stresses the general adaptive function of positive emotions and posits that enhanced experiences of positive emotions foster subjective well-being and other beneficial outcomes (e.g., Bryant & Veroff, 2007; Fredrickson, 2001; Lyubomirsky et al., 2005). The second line of work – research on affect dynamics – emphasizes the dynamic nature of affect and proposes people's changing affective experiences and underlying affective processes to be central mechanisms underlying the development of well-being (e.g., Hollenstein et al., 2013; Wichers, 2014). Even though both lines of work have remained rather separable in the literature – and have been presented here accordingly – theories from both lines of work are concerned with how short-term affective processes over time may translate into more enduring emotional outcomes. That is, people's affective responses in certain situations and their specific affective experiences in everyday life may impact the development of subjective well-being. For example, the cumulative impact of enhanced affective reactions each time a positive event occurs, may over time maintain or even increase subjective well-being. Thus, zooming on the psychological and physiological processes underlying people's changing affective experiences and behaviors poses one way to better understand subjective well-being and interindividual differences therein. The present dissertation investigates two affective processes – affective reactivity and emotion regulation –thought to underlie short-term changes in *positive* affective experiences and relates these to interindividual differences in *subjective well-being* (Figure 1).

This approach mirrors research on negative affect dynamics and lower well-being, and psychopathology in particular. Here, studies established a relation between, for example, an enhanced affective reactivity to negative events in daily life and lower levels of well-being and poorer health (Affleck, Tennen, Urrows, & Higgins, 1994; Myin-Germeys, van Os, Schwartz, Stone, & Delespaul, 2001; Sin, Graham-Engeland, Ong, & Almeida, 2015). Similarly, an inability to regulate one's negative emotions has been associated with several forms of psychopathology, such as mood and anxiety disorders (Aldao, Nolen-Hoeksema, & Schweizer, 2010; Joormann & Gotlib, 2010). Finally, studies from the affective neurosciences have made substantial progress in establishing the neural correlates of the affective processes underlying negative affective experiences. For example, engaging in cognitive reappraisal, one commonly used strategy to down-regulate negative emotions, has been

shown to recruit cognitive control regions (e.g., dorsolateral, dorsomedial, and ventrolateral prefrontal cortex) and the amygdala (Buhle et al., 2014). Variations in these neural activations have also been associated with clinical disorders, such as enhanced amygdala activation during the down-regulation of positive emotions in participants with mood disorders (Zilverstand, Parvaz, & Goldstein, 2017).

In the following, I will outline the processes of affective reactivity and emotion regulation at both the level of subjective experience and the neural level. I will then describe their potential relation to interindividual differences in subjective well-being, and especially higher subjective well-being. For this, literature from both psychology and the affective neurosciences is reviewed and specific open research questions are identified. Finally, it is elaborated on how the use of multiple methods (e.g., behavioral, neuroimaging, experience-sampling) helps to get a more complete understanding of the affective processes under investigation.

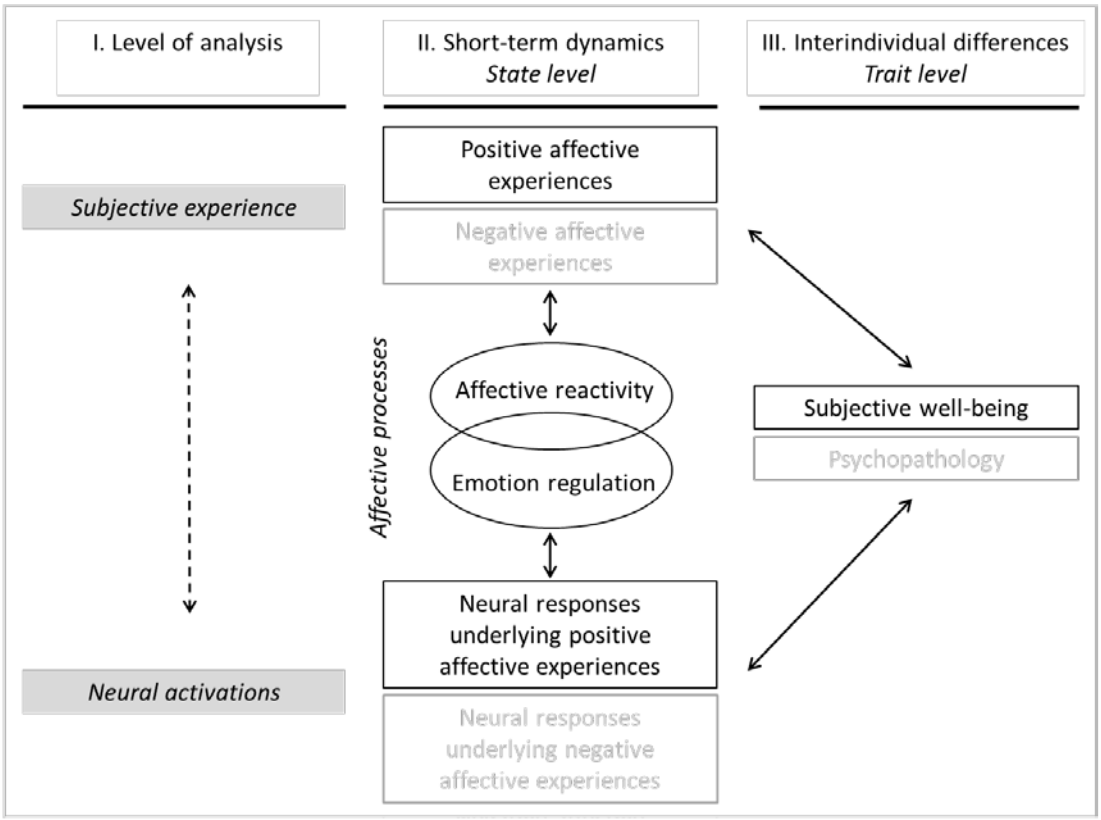

Figure 1. Central variables investigated in this dissertation. Paths reflect assumed influences between the different variables. Relations between negative affect dynamics and psychopathology, as established by previous research, are marked in light grey.

4 Affective Reactivity and Emotion Regulation

Before turning to affective reactivity and emotion regulation in more detail, it is important to delineate them. Affective reactivity is generally defined as the spontaneous response to an event or stimulus, whereas emotion regulation is defined as the process that modifies (e.g., increases or decreases) the affective reaction in accordance with one's regulation goal (Gross, 1998; Gross & Thompson, 2007). In such dual-process approach (Chaiken & Trope, 1999; Sloman, 1996), affective reactivity generally represents an *automatic* and effortless process and emotion regulation a *controlled* processes that requires conscious effort for initiation (Gross, 1998; Gross & Thompson, 2007). Even though the affective neurosciences have not fully determined the neural circuits that underlie the complexities of the affective processes, they generally support the idea of separating automatic reactions from controlled regulatory processes (Etkin, Büchel, & Gross, 2015; Ochsner, Silvers, & Buhle, 2012).

It is further distinguished between implicit (or automatic) and explicit (or deliberate) emotion regulation, with the former being a regulation process that occurs outside of awareness (Etkin et al., 2015; Gyurak, Gross, & Etkin, 2011). However, as implicit emotion regulation – similar to affective reactivity – also reflects an automatic affective process, this further distinction is not made here, and the present dissertation solely focuses on explicit emotion regulation.

It is important to note, that it has been subject to debate in the psychology of emotions and related disciplines, to what extent affective reactivity and emotion regulation can be separated at all (Gross & Barrett, 2011; Kappas, 2011). From a theoretical perspective, an answer depends on one's definition of emotion in general (Gross & Barrett, 2011). For example, according to basic emotion theories, there is a clear distinction between affective reactions and regulation processes, as these two processes are assumed to have unique physiological substrates (Panksepp, 2004). Following psychological constructionist theories, in contrast, a distinction between affective reactivity and emotion regulation seems superfluous, as emotions are generally viewed as mental states that are constantly modified (Barrett, 2009). From an empirical perspective, a distinction between affective reactivity and emotion regulation (in contrast to viewing them as one integrative process) would be indicated if it helps to explain additional variance of the phenomenon under investigation. Affective

reactivity, as an automatic process, is more innate and therefore influenced by implicit factors, such as previous experiences, habits or implicit hedonic goals (Mauss, Bunge, & Gross, 2007). Emotion regulation, as a controlled process, is more influenced by cognitive capacities, such as working memory function, which is essential to cognitively monitor the affective reaction (Etkin et al., 2015). Considering these different influencing factors, it is reasonable to assume that affective reactivity and emotion regulation might differentially shape the subjective experience of positive affective states and therefore might not be identically linked to interindividual differences in subjective well-being.

In this dissertation, I therefore follow this rather functional approach and distinguish between affective reactivity and emotion regulation – both when reviewing the literature and in my empirical studies. However, not without acknowledging that these affective processes are certainly strongly related and even intertwined. Therefore, in most situations, especially in daily life, affective experiences are rooted in a complex interplay between our spontaneous affective reactions and regulatory efforts.

4.1 Affective Reactivity to Positive Events

4.1.1 Subjective Experience

As outlined above, affective reactivity can be defined as the spontaneous affective response to an event or stimulus that gives rise to multifaceted responses in subjective experience, behavior, cognition, and neurophysiology (Gross, 1998; Gross & Thompson, 2007). Affective reactions are automatically triggered by an emotionally relevant event that (consciously or unconsciously) is appraised as positive or negative and is subsequently acted upon (Gross & Thompson, 2007; Ochsner & Barrett, 2001). A positive appraisal is made when a physiological need is fulfilled, a goal is attained (or a goal-inconsistent state reversed), or a specific outcome exceeds one's expectations (Cohn & Fredrickson, 2009). Thus, in accordance with the appraisal perspective on emotion (Lazarus, 1991), an affective reaction to an event leads to increases in positive affect, if the valuation of a stimulus or a situation is positive (i.e., rewarding). It is important to note that even though affective reactions to positive events are thought to predominantly increase positive affect, at the within-person level of analysis positive and negative affect are not conceived as completely independent (Brose, Voelkle,

Lövdén, Lindenberger, & Schmiedek, 2015). Thus, affective reactions to positive events not only increase positive affect, but, at least to some extent, also lead to decreases in negative affect (Zautra, Affleck, Tennen, Reich, & Davis, 2005).

It has been recognized that there are substantial differences across people in their strength of affective reactions (Davidson, 1998; Kuppens et al., 2010). Past research has aimed at accounting for these interindividual differences. For example, conceptualized as the within-person relation between daily affect and self-reported daily events, affective reactions to positive events have been shown to be stronger in younger, as compared to older people in one daily diary study (Röcke et al., 2009). Similarly, personality, and extraversion in particular, has been related to the strength of affective reactions to positive events. In the laboratory, higher levels of extraversion have been related to enhanced affective reactions to positive stimuli, as assessed through the change in positive affect after a positive mood induction procedure (i.e., mental imagery task; Larsen & Ketelaar, 1991). However, studies conducted in daily life could not confirm these findings (Howell & Rodzon, 2011; Lucas, Le, & Dyrenforth, 2008). Together, these studies show that the strength of affective reactions to positive stimuli and events, as measured in the laboratory and in daily life, relates to interindividual difference variables.

4.1.2 Link to Subjective Well-Being

Following the idea that enduring emotional outcomes, such as subjective well-being, may reside in the short-term processes underlying specific affective experiences and behaviors in everyday life (e.g., Hollenstein et al., 2013), the strength of affective reactions to positive events should also relate to interindividual differences in subjective well-being. More specifically, given the presumed beneficial effects of intense positive affective experiences for subjective well-being (Bryant, 2003; Bryant & Veroff, 2007; Fredrickson, 2001), especially an enhanced affective reactivity to positive events should be related to higher levels of subjective well-being. However, across several literatures (e.g., positive psychology, personality psychology, aging and clinical literature) and both laboratory and daily life studies, empirical data about the link between affective reactivity to positive events and interindividual differences in subjective well-being is mixed. While some evidence points to enhanced

affective reactivity in participants with higher subjective well-being (Carl et al., 2014; Larsen & Ketelaar, 1991), other evidence points in the opposite direction, that is, reduced affective reactivity to positive events (Oishi et al., 2007; Röcke et al., 2009). Similarly, one study showed depressed participants to have reduced affective reactivity to positive stimuli in the laboratory (Bylsma et al., 2008), while another study found enhanced affective reactivity to daily positive events in people with major depressive disorder (Bylsma, Taylor-Clift, & Rottenberg, 2011). While the finding of reduced affective reactions to positive events in people with higher subjective well-being seems surprising in light of theories from positive psychology, there are theoretical considerations that possibly explain these findings. For example, according to the opponent process theory (Solomon, 1980), for one to experience intense positive affect, it is necessary to first experience intense negative affect. Along these lines, affect intensity, a stable individual difference characteristic of how strongly one usually experiences affect, has been shown to apply to both valences (Larsen & Diener, 1987). Thus, individuals who experience intense positive affect usually also experience intense negative affect. These theoretical notions imply that enhanced affective reactions to positive events might carry emotional costs, explaining why they could be related to lower levels of subjective well-being. Additionally, the findings on a relatively greater emotional stability in people with higher subjective well-being (Houben et al., 2015) may indicate that less deviation from one's baseline in the face of positive events (i.e., reduced affective reactivity) is also related to higher subjective well-being.

In sum, previous research yielded two different pictures of the relationship between affective reactivity to positive events and interindividual differences in subjective well-being. Moreover, available evidence differs widely in regard to methodological approaches (e.g., laboratory versus daily life studies) and indicators of well-being (e.g., indicators of subjective well-being versus clinical diagnoses). Hence, it remains an open question of whether an enhanced or reduced affective reactivity to positive events relates to higher levels of subjective well-being.

4.1.3 Neural Level

Several cortical and subcortical regions are generally assumed to be involved in automatic affective processing and assumed to underlie affective reactions to emotional stimuli and events

(Lindquist, Wager, Kober, Bliss-Moreau, & Barrett, 2012; Ochsner et al., 2012): For example, the brainstem as well as limbic and paralimbic regions, including the amygdala, the hippocampus, the cingulate cortex, the insula, and the basal ganglia have been frequently found active during affective processing. Besides the broad evidence linking these brain regions to the general experience of emotion (e.g., Kober et al., 2008; Lindquist et al., 2012), it is not yet clear how neural activations in these brain regions are related to the experience of positive and negative affective states. A recent proposition – the affective workspace hypothesis – suggests that a general and large-scale affective network underlies both positive and negative affective experiences (Lindquist, Satpute, Wager, Weber, & Barrett, 2016). Meta-analytic results supported such valence-general affective network (largely comprising the regions mentioned above), which is active during both positive and negative affective experiences with valence being flexibly implemented in different patterns of activation across regions of this network (Lindquist et al., 2016). Besides this general implication of these brain regions in affective processing, specifically the amygdala and the ventral striatum (VS) seem to be central to the experience of positive and negative affect, due to their involvement in the processing of threat and reward, respectively (Berridge & Kringelbach, 2013; Buhle et al., 2014).

The VS (including the nucleus accumbens) is a part of the basal ganglia and a main input site of dopaminergic projections from the ventral tegmental area and the substantia nigra (Graybiel, 2000). As a central part of the brain's reward circuit, the VS is mainly known for its role in reward processing and reward-related behavior in both non-human animals (Apicella, Ljungberg, Scarnati, & Schultz, 1991) and humans (Berridge & Kringelbach, 2008; Delgado, 2007; Haber & Knutson, 2010). For instance, VS activity has been linked to the anticipation of taste-based (O'Doherty, Deichmann, Critchley, & Dolan, 2002) or monetary rewards (Knutson, Fong, Adams, Varner, & Hommer, 2001; Knutson, Fong, Bennett, Adams, & Hommer, 2003). Additionally, increased activation in the VS is related to the attainment of rewards (Delgado, Locke, Stenger, & Fiez, 2003; Delgado, Nystrom, Fissell, Noll, & Fiez, 2000) and decreased activation in the VS with the omission of expected rewards (Berns, Mcclure, Pagnoni, & Montague, 2001; Knutson et al., 2001). From a psychological perspective, rewards are assumed to induce a feeling of pleasure and therefore contribute to the subjective experience of positive affect (Ashby & Isen, 1999; Schultz, 2000). Indeed, a study showed

that momentary happiness ratings were accounted for by one's subjective responses to rewards, as reflected in BOLD-signal in the VS (Rutledge, Skandali, Dayan, & Dolan, 2014). Along these lines, studies have reported increased VS activity in response to various positive stimuli, such as pleasant music (Blood & Zatorre, 2001), smiling faces (Vrtička, Andersson, Grandjean, Sander, & Vuilleumier, 2008), positive images (Sabatinelli, Bradley, Lang, Costa, & Versace, 2007), or positive autobiographical memories (Speer, Bhanji, & Delgado, 2014). Together, these findings underline the role of the VS for affective reactivity to positive stimuli and events.

On a more general note, previous studies have demonstrated that there are differences across individuals in their neural responses to rewards and that these relate to stable person characteristics, such as psychopathic (Buckholtz et al., 2010) or affective traits (Wu, Samanez-Larkin, Katovich, & Knutson, 2014). A recent study even found differences in VS activity in response to monetary rewards to be positively linked to well-being, as indicated by well-being composite scores (which included measures of life satisfaction and trait positive affect; Morelli, Knutson, & Zaki, 2018). These findings therefore give first indication, that differences in one's neural responses to rewards might not only relate to momentary affective experiences, but may also account for more stable differences in emotion, such as subjective well-being.

4.2 Up-Regulation of Positive Emotions

4.2.1 Subjective Experience

Emotion regulation can be defined as the process "by which individuals influence which emotions they have, when they have them, and how they experience and express these emotions" (Gross, 1998, p. 275). Conceptualized this way, emotion regulation modifies the trajectory of the initial affective reaction through the implementation of controlled regulatory processes (Gross, 1998; Gross & Thompson, 2007). Various models have emerged that aim at classifying the different ways and strategies people use to regulate their emotions. These, for example, differentiate strategies based on the temporal specificities of where they target the emotional trajectory (Gross, 1998, 2015) or based on the target and function of the regulation process (Koole, 2009).

Regarding the regulation of positive emotions, most people aim at up-regulating or prolonging their positive affective experiences (Gross, Richards, & John, 2006). This finding is in line with the notion that people are generally pro-hedonically motivated, that is, they want to feel good most of the times (Riediger et al., 2009). When regulating positive emotions, affective reactions and regulatory processes usually work through reciprocal reinforcement (Jose et al., 2012), rather than compete against each other as during the down-regulation of negative emotions (Sheppes & Gross, 2011). However, people also sometimes down-regulate their positive emotions (e.g., in pursuit of a goal; Tamir, 2009).

The savoring account, as outlined above (cf. 2.2), not only describes the general mechanisms with which people derive joy from their positive experiences; it can also serve as a framework for specific up-regulation processes that generate, maintain, or enhance positive affective experiences (Bryant, 2003; Bryant & Veroff, 2007). When engaging in savoring, one attends to and appreciates past, present and future positive moments in life (Bryant, 2003). For example, through *being present* in the moment, one can savor current positive emotions, while *positive mental time travel* can enhance past or future positive experiences (Nelis, Quoidbach, Hansenne, & Mikolajczak, 2011).

Empirical studies conducted in daily life showed that savoring the present moment relates to increases in momentary levels of affect. For example, savoring positive events in daily life has been related to increases in self-reported momentary happiness (Jose et al., 2012) and the number of up-regulation strategies one uses has been positively associated with subsequent mood ratings (Heiy & Cheavens, 2014). Even though laboratory assessments of the up-regulation of positive emotions are scarce, one study showed that, compared to simply reacting to, up-regulating emotions in response to amusing film clips led to increases in the subjective experience of amusement, as well as facial expressions and autonomic physiology (e.g., heart rate and sympathetic nervous system activation) related to amusement (Giuliani, McRae, & Gross, 2008). Taken together, engaging in the deliberate up-regulation of positive emotions is one of the means through which positive affective experiences can be successfully enhanced, as indicated by increases in positive affect in the laboratory and in daily life.

4.2.2 Link to Subjective Well-Being

Building upon theoretical notions that stress the role of the short-term affective processes for the development of subjective well-being (e.g., Hollenstein et al., 2013), and the importance of intense positive affective experiences in particular (Bryant, 2003; Bryant & Veroff, 2007; Fredrickson, 2001), greater increases in positive affect when up-regulating one's positive emotions (i.e., greater success in up-regulating positive emotions) should relate to higher levels of subjective well-being.

Several studies provide first evidence that the up-regulation of positive emotions is indeed positively related to subjective well-being. The frequent use of savoring strategies has been shown to be positively correlated with life satisfaction and happiness ratings (Bryant, 2003) and another study showed that the typical use of up-regulation strategies was related to both affective and cognitive indicators of subjective well-being (Quoidbach, Berry, Hansenne, & Mikolajczak, 2010). Along these lines, clinical research has shown that deficits in positive emotion regulation are a characteristic of various emotional disorders, such as mood and anxiety disorders (Carl et al., 2014). Together, these studies established a positive relation between trait levels of emotion regulation, indicative of habitual or typical emotion regulation behavior, and interindividual differences in subjective well-being. However, it remains unknown how actual within-person changes in positive affect when up-regulating positive emotions, as assessed through self-reports of momentary affective experiences, relate to interindividual differences in subjective well-being.

4.2.3 Neural Level

In accordance with the conceptualization of emotion regulation as an effortful process that requires some level of control for initiation, most neural models of emotion regulation focus on the interaction between neural cognitive control systems and neural circuits involved in affective reactions to stimuli and events (Etkin et al., 2015; Ochsner et al., 2012). Meta-analyses have shown that (e.g., dorsolateral, ventrolateral and dorsomedial) prefrontal and (mainly anterior) cingulate cortices, otherwise associated with various cognitive control functions and working memory more generally (Ochsner & Gross, 2008), modulate activation in subcortical areas (e.g., the amygdala), which are associated with affective reactions (Buhle et al., 2014; Kohn et al., 2014). Most research focused on

the down-regulation of negative emotions, particularly using cognitive reappraisal. The theoretical notions and empirical findings from this research can be used as a foundation for understanding the neural correlates of the deliberate up-regulation of positive emotions.

While most studies found cognitive reappraisal and cognitive control regions to decrease activation in the amygdala (e.g., Buhle et al., 2014), some studies found that regulatory efforts additionally modulated, namely increased, activity in the VS (McRae, Ochsner, Mauss, Gabrieli, & Gross, 2008; Wager, Davidson, Hughes, Lindquist, & Ochsner, 2008). The authors speculated that this increase in VS activity reflects an increase in positive affect. That is, fMRI data suggests that when engaging in cognitive reappraisal, participants not only reduce their negative but also enhance their positive affect. This assumption has been supported by studies that investigated regulation strategies that specifically aim at increasing positive emotions in negative contexts. These studies showed that activity in the VS was positively associated with the enhanced experience of positive affect during positive reappraisal (Doré et al., 2017) and increased when engaging in compassion-based up-regulation of positive emotion (Engen & Singer, 2014). Following this, hypotheses can be derived on brain regions underlying enhanced positive emotional experiences during the up-regulation of positive emotions. That is, to the extent that engaging in the up-regulation of positive emotions (in positive contexts) successfully enhances positive affect, it should also increase activation in the VS.

Indeed, the few studies that used fMRI to investigate the up-regulation of positive emotions, observed, next to activation in medial and lateral prefrontal areas, similar to the down-regulation of negative emotion, increased activation in the VS (Greening et al., 2014; Kim & Hamann, 2007; Li et al., 2018; Moutsiana et al., 2014; Vrticka, Sander, & Vuilleumier, 2011). On study also reported a positive relation between VS activity and interindividual differences in levels of positive affect when up-regulating (i.e., mean levels of positive affect across all regulation trials compared to control trials; Greening et al., 2014). These studies suggest that enhancing positive affective experiences through the successful up-regulation of positive emotions increases activation in the VS. However, it is not yet known whether the increased activation in the VS reflects interindividual differences in the general capacity to up-regulate positive emotions or whether VS activity also reflects dynamic within-person changes in positive affective experiences during up-regulation (i.e., trial-to-trial changes).

Examining how VS activity relates to within-person changes in affect during the up-regulation of positive emotions not only helps to delineate this regulation process at the neural level, but may also help to get a better understanding of subjective well-being and interindividual differences therein. Several neuroimaging studies suggest people with major depressive disorder to be characterized by VS dysfunction during the regulation of positive emotions. In one study, depressed participants showed dissociable effects between VS activity and levels of positive affect when up-regulating positive emotions, suggesting that VS recruitment does not successfully modulate affective experiences in these participants (Greening et al., 2014). In another study, participants with major depressive disorder failed to sustain VS activity (i.e., over the course of the fMRI session) when instructed to up-regulate their positive emotions, and this failure was accompanied by less self-reported positive affect (Heller et al., 2009). Though, no study to date has related VS activity during the up-regulation of positive emotions to levels of subjective well-being, the above findings underline the importance of taking neural activations into account when aiming to understand the processes underlying well-being.

5 Affective Reactivity and Emotion Regulation: A Multimethod Approach

Both laboratory-based experiments and studies conducted in more naturalistic settings can inform us about the affective processes underlying short-term changes in positive affective experiences and their relation to interindividual differences in subjective well-being. Through experimental manipulations in the laboratory, it is possible to gain a more mechanistic understanding of a specific affective process. This way, neuroimaging studies, for example, can uncover when and to what extent specific brain regions are engaged during a particular emotion regulation process (Ochsner & Gross, 2008). Yet, their rigor usually comes with the loss of generalizability of findings to the "real world" (Araújo, Davids, & Passos, 2007; Wilson, Aronson, & Carlsmith, 2010). With methods, such as the experience-sampling (Csikszentmihalyi & Larson, 1987) or the daily reconstruction method (Kahneman, Krueger, Schkade, Schwarz, & Stone, 2004), it is possible to repeatedly sample affective experiences and behaviors as they unfold in everyday life, allowing the study of affective processes with greater ecological validity (Ebner-Priemer & Trull, 2009). Together, each research approach

comes with its unique strengths and is therefore best designed for answering specific research questions.

However, with most studies focusing exclusively on either of the methods, it remains an open question of how findings from these two reconcile. A meta-analysis found that effect sizes from laboratory and daily life studies were only moderately correlated, with a number of them even changing their direction of effect (Mitchell, 2012). Such possible divergence between laboratory and daily life findings can also be exemplified by research in the psychology of emotions. For example, as outlined above people with major depressive symptoms have been shown to have reduced affective reactions to positively valenced stimuli in the laboratory (Bylsma et al., 2008), but enhanced affective reactivity to positive events in daily life (Bylsma et al., 2011). Along similar lines, a meta-analysis of laboratory studies showed that experimentally induced expressive suppression is effective in reducing negative affect (Webb, Miles, & Sheeran, 2012). In contrast, first evidence suggests that the use of expressive suppression in daily life is associated with increases in negative feelings (Brans, Koval, Verduyn, Lim, & Kuppens, 2013). These examples illustrate how the investigation of affective processes can yield divergent findings, which may be due to the use of different research methods. Studying affective processes in both the laboratory and in daily life within the same sample may help to parcel out the method-based roots of potential discrepancies in findings and may help to reach a more comprehensive understanding of the phenomenon under investigation.

Only few studies, to date, have taken such approach. Combined experimental research in the laboratory with experience-sampling in daily life found increased emotional inertia to be associated with a slower return to baseline of negative affect using these two methods (Koval et al., 2015). Similarly, an fMRI study showed that sustained activation in the VS during the experience of reward in a gambling task was related to prolonged positive affect during a smartphone-based gambling task in daily life (Heller et al., 2015). These studies provide an important first step in integrating laboratory and daily life research designs, but for most psychological phenomena and processes, it is not yet clear how laboratory findings translate into measures in daily life.

6 Summary of Aims and Research Objectives

The overarching aim of this dissertation is to better understand interindividual differences in subjective well-being through an investigation of the affective processes – affective reactivity and emotion regulation – underlying short-term changes in positive affective experiences. This approach follows a dynamic perspective on the study of individual differences and the proposition that interindividual differences in well-being emerge from affect dynamics (e.g., Hollenstein et al., 2013). It is also in accordance with theoretical notions from positive psychology that suggest positive affective experiences to play a pivotal role in the development of subjective well-being (Bryant, 2003; Bryant & Veroff, 2007; Fredrickson, 2001).

Regarding the relationship between affective reactivity to positive events and subjective well-being, theoretical and empirical work shows a mixed picture. Based on work from positive psychology that highlights the beneficial effects of intense positive affective experiences for high subjective well-being (e.g., Carl et al., 2014; Fredrickson, 2001), I would expect enhanced affective reactivity to positive events to be related to higher subjective well-being. Yet, in accordance with other theoretical notions that, for example, point to potential emotional costs of intense positive experiences (e.g., Solomon, 1980) and work that shows greater emotional stability and less variable affective experiences to relate to higher subjective well-being (e.g., Houben et al., 2015), I would expect people with higher subjective well-being to show reduced affective reactivity to positive events. Taking these different pictures of the link between affective reactivity to positive events and subjective well-being into account, I test both respective hypotheses in the empirical studies in this dissertation. That is, I test whether enhanced or reduced affective reactivity is related to higher subjective well-being.

A potential link between the up-regulation of positive emotions and subjective well-being is mainly informed by research from positive psychology that underlines the adaptive function of high positive affect for subjective well-being (Fredrickson, 2001) and the capacity to up-regulate positive affective experiences in particular (Bryant, 2003; Bryant & Veroff, 2007). Based on this, I hypothesize greater increases in positive affect when up-regulating positive emotions (i.e., greater success in up-regulating positive emotions) to relate to higher subjective well-being.

The empirical approach of this dissertation was as follows: First, through observations at the subjective and the neural level, the affective processes of affective reactivity and emotion regulation, and their potential relation to interindividual differences in subjective well-being were investigated. Second, different research methods were combined and integrated in the empirical studies. Laboratory-based methods were used to gain a more mechanistic understanding of the processes under investigation and daily life research methods were used to capture the processes under "natural" circumstances. The details of the research objectives of the studies are summarized below and the combined approach of different levels of analysis and methods is illustrated in Figure 2.

The first research objective was to test how affective reactivity and successful up-regulation of positive emotions in the laboratory relate to interindividual differences in subjective well-being (*Paper I*). In line with the approach of this dissertation to capture affective reactivity and emotion regulation as they occur within individuals, I assessed participants' momentary positive affective experiences, while they were instructed to react and to up-regulate in response to positive film-clips. The use of performance-based indicators of affective reactivity and emotion regulation that capture actual within-person changes in positive affect extends previous studies that established a positive relation between subjective well-being and self-report measures of reactivity (e.g., Carl et al., 2014) and positive emotion regulation (e.g., Bryant, 2003). In addition, trait levels of emotion regulation were assessed. I hypothesized that greater increase in positive affect when reacting to the positive film clips and when up-regulating positive emotions, relate to higher subjective well-being. Exploratively, I investigated the relation between these changes in affect when up-regulating (i.e., performance-based indicators of emotion regulation) and trait levels of emotion-regulation.

The second research objective was to examine the neural correlates underlying the successful up-regulation of positive emotions in the laboratory and in daily life (*Paper II*). Previous studies related VS activity to affective reactions to positive stimuli (e.g., Vrtička et al., 2008) and to differences in affect in the successful up-regulation of positive emotions across people (Greening et al., 2014). Extending this, it was specifically tested in this study whether activation in the VS also relates to within-person changes in positive affect (i.e., trial-to-trial changes in affect) when up-regulating. Following the empirical approach of this dissertation to combine different methods, it was

further tested whether increased VS activity during the up-regulation of positive emotions in the laboratory relates to increased changes in affect when up-regulating in daily life, as captured through the experience-sampling method.

Finally, a third research objective concerned the inconsistent picture of the relation between affective reactivity to positive events and subjective well-being. Empirical studies supported either a link between enhanced or reduced affective reactions to positive events and higher subjective well-being. While that latter seems surprising given the suggested role of intense positive experiences in higher subjective well-being, it aligns with other theoretical work that stresses the emotional costs resulting from more extreme affective experiences (e.g., Solomon, 1980). Given these opposing theoretical predictions and diverse empirical findings, the third research objective of this dissertation was to provide a large-scale and systematic empirical test of the relationship between affective reactivity to positive events and interindividual differences in subjective well-being (Grosse Rueschkamp et al., 2018). More specifically, across six studies that all captured positive event occurrence and momentary affect in daily life via the experience-sampling or daily diary method, as well as trait levels of well-being, it was tested whether higher subjective well-being is related to enhanced or reduced affective reactivity to positive events.

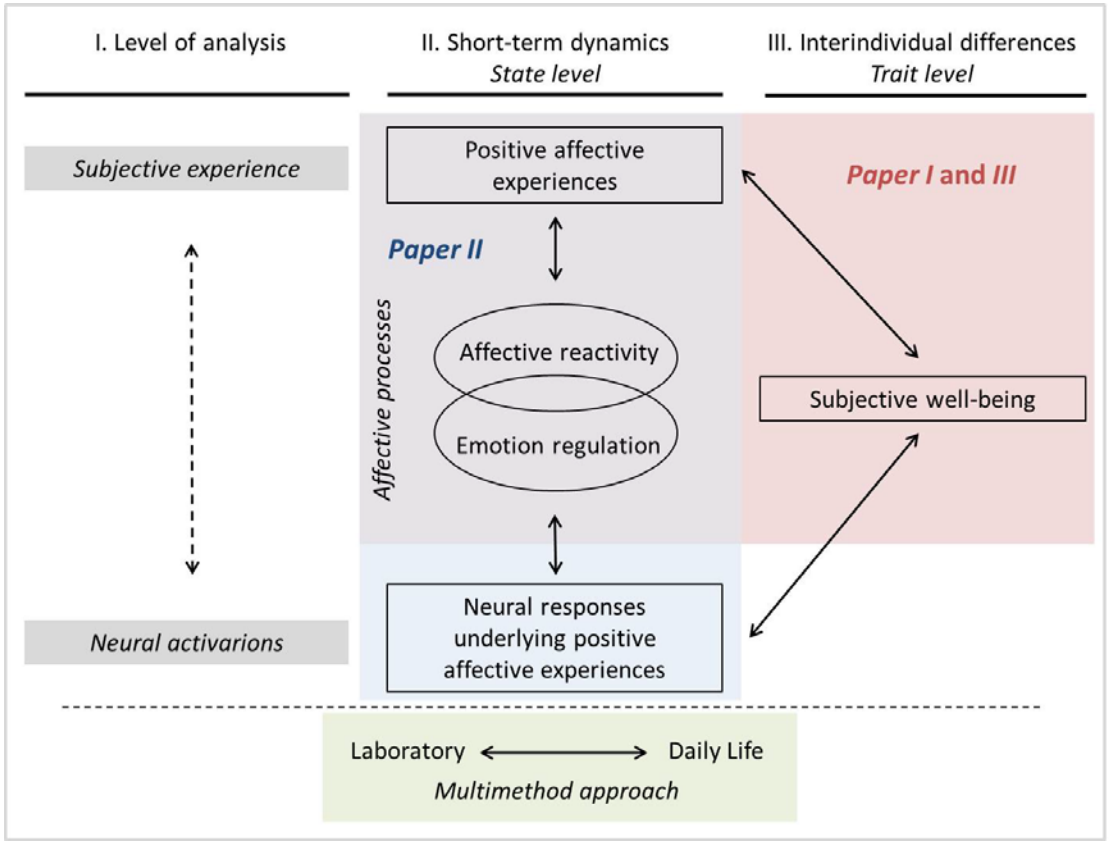

Figure 2. Central variables investigated in this dissertation and research objectives addressed in the empirical studies (*Papers I, II* and *III*). Paths reflect assumed influences between the different variables. The multimethod approach encompassed research designs the laboratory and in daily life both across and within studies.

7 Paper I

Two Sides of the Same Coin? Only Self-Reported, but not Performance-Based Regulation of Positive Emotions Relates to Subjective Well-Being

Johanna M. Grosse Rueschkamp

Humboldt-Universität zu Berlin, Germany

Elisabeth S. Blanke

Humboldt-Universität zu Berlin, Germany

Annette Brose

Humboldt-Universität zu Berlin, Berlin, Germany

Author Note

The research leading to the results reported in this paper was supported in part by a grant awarded to Annette Brose by the German Research Foundation [Deutsche Forschungsgemeinschaft, DFG], BR 3782/3-1, as well as by a grant from the Humboldt Graduate School "Self-Regulation Dynamics Across Adulthood and Old Age: Potentials and Limits", Humboldt-Universität zu Berlin, awarded to Johanna M. Grosse Rueschkamp. Johanna M. Grosse Rueschkamp is a pre-doctoral fellow of the International Max Planck Research School on the Life Course (LIFE, www.imprs-life.mpg.de).

Correspondence concerning this article should be addressed to Johanna M. Grosse Rueschkamp, Humboldt-Universität zu Berlin, Institut für Psychologie, Emmy Noether Independent Junior Research Group “Adaptation to Major Life Events,” Unter den Linden 6, 10099 Berlin, Germany. Email: johanna.grosserueschkamp@hu-berlin.de

Abstract

Theories suggest that the up-regulation of positive emotions is important for well-being. However, with previous studies focusing on self-reported habitual up-regulation, it remains unknown how subjective well-being is related to up-regulation *success*, as indicated by performance-based measures of emotion regulation. In the present study, 183 participants were instructed to either up-regulate their emotions or to react to amusing film clips, while providing ratings of their positive affect. Subjective well-being and habitual emotion regulation were assessed via self-reports. While we did not find evidence for a relation between up-regulation success and subjective well-being, greater habitual emotion regulation was associated with higher subjective well-being. These findings suggest that people who report to up-regulate their positive emotions more frequently not necessarily do so more successfully, and only the former seems to be characteristic of higher subjective well-being. These results point to the importance of integrating different methods in the study of emotion regulation.

Keywords: subjective well-being, up-regulation, positive emotions, regulation success, habitual emotion regulation

Successful emotion regulation is suggested to be a crucial part of well-being and resilience (Gross & John, 2003). This is best made explicit by the fact that maladaptive emotion regulation in the context of negative experiences is associated with several forms of psychopathology, such as mood and anxiety disorders (e.g., Aldao, Nolen-Hoeksema, & Schweizer, 2010; Joormann & Gotlib, 2010). Similarly, successful down-regulation of negative emotions has been related to higher levels of subjective well-being (e.g., Côté, Gyurak, & Levenson, 2010; McRae, Jacobs, Ray, John, & Gross, 2012). However, in daily life, people not only down-regulate their negative, they also attempt to enhance their positive affective experiences (Gross et al., 2006). First evidence indicates that the latter might also be crucially important for well-being, as the frequent or habitual up-regulation of positive emotions has been linked to higher subjective well-being (e.g., Quoidbach, Berry, Hansenne, & Mikolajczak, 2010). However, it is not yet clear whether habitual up-regulation also indicates up-regulation success (i.e., how strongly one actually increases positive affect when up-regulating). As an enhanced experience of positive emotions is thought to be particularly beneficial for physical and psychological well-being (Fredrickson, 2001), greater up-regulation success should be related to higher subjective well-being – the experience of predominantly positive emotions and a positive evaluation of one's life (Diener, Suh, Lucas, & Smith, 1999). The aim of the present study was to investigate this hypothesized link between subjective well-being and up-regulation success, indicated by a performance-based measure of emotion regulation in the laboratory, and to explore how up-regulation success relates to habitual emotion regulation.

Emotion regulation has been defined as the process by which people influence the nature, the frequency and the duration of their emotions (Gross, 1998; Gross & Thompson, 2007). For example, people can try to change the meaning of an emotion eliciting stimulus (Ochsner, Bunge, Gross, & Gabrieli, 2002) or they can aim at altering their behavioral response to a certain stimulus (Gross, 2002) in order to reduce or enhance the emotional response. There is reason to believe that the deliberate enhancement of affective experiences may be important for well-being. Within the study of positive psychology, theories have emerged that promote the role of positive emotions in positive functioning and subjective well-being, specifically higher subjective well-being. One of these propositions

suggests that the increased experience of positive emotions broaden people's attention and thinking in ways that, on the long run, enable people to build a host of personal resources (cognitive, psychological, social, and physical; Fredrickson, 2001). These resources, in turn, are thought to positively influence subjective well-being. Thus, experiencing intense positive emotions may have benefits for subjective well-being. This general idea has been supported by studies which, for example, indicate that people with higher global positive affectivity show a heightened reactivity to positive events (Carl et al., 2014). Yet, people do not only react to positive events with positive emotions, they may also further up-regulate their positive affective experiences (Bryant, 2003). This process of deliberately maximizing positive affective experiences – termed savoring – has been defined as a self-regulatory mechanism that aims at the generation, maintenance, or enhancement of positive affect, and has been proposed to increase subjective well-being (Bryant, 2003; Bryant & Veroff, 2007). Thus, people who are more attuned to their positive emotions and more appreciative of the positive moments in their life enjoy these moments more and for a longer period of time and should therefore have higher levels of subjective well-being.

Empirical studies support this proposed link between an enhanced up-regulation of positive emotion and higher levels of subjective well-being. The use of several savoring strategies (Quoidbach et al., 2010), as well as higher frequency of up-regulating (Livingstone & Srivastava, 2012) have been positively associated with various indicators of cognitive and affective well-being. Additionally, a stronger belief in one's own ability to up-regulate positive emotions has been related to greater life satisfaction and happiness (Bryant, 2003; Smith & Hollinger-Smith, 2015). Finally, along these lines, first evidence indicates that symptoms of depression are related to the less frequent use of up-regulation strategies (Nelis et al., 2011). Taken together, these studies support the claim for a positive relationship between the up-regulation of positive emotions and subjective well-being. These studies all investigated habitual emotion regulation, that is, typical or average regulation behaviors. Habitual emotion regulation is usually measured through self-reports that require participants to make judgments across various contexts and therefore only reflect quite global evaluations of specific behaviors. Thus, these measures of habitual emotion regulation are not indicative of how succesfully

one up-regulates positive emotions, that is, how strongly one actually enhances positive affective experiences when up-regulating.

To the contrary, there are indeed a few studies that have investigated the up-regulation of positive emotions using performance-based indicators of regulatory success. One of the studies showed that the instructed up-regulation of emotions to amusing film clips in the laboratory was related to increases in the emotional experience and facial expression of amusement, as well as increases in amusement-related physiology as compared to mere emotional reactivity to such clips (Giuliani et al., 2008). Similarly, in another study, up-regulating emotions in response to positive images resulted in enhanced levels of self-reported affect (Kim & Hamann, 2007). These studies show that engaging in up-regulation efforts can lead to an increase in positive feelings, and that quantifiying this increase in positive feelings provides a performance-based indicator of successful emotion regulation. Yet, to date it remains unknown how the successful up-regulation of positive emotions (i.e., increases in positive affect when up-regulating) relates to subjective well-being. In accordance with current theories of positive psychology (cf. Bryant & Veroff, 2007; Fredrickson, 2001), it can be expected that comparatively greater regulatory success is related to relatively high levels of subective well-being.

The Present Study

The aim of the present study was to investigate individual differences in the successful up-regulation of positive emotions, as indicated by a performance-based measure of emotion regulation in the laboratory, and to relate these to differences in subejctive well-being. We instructed participants to either simply react (reactivity condition) or to up-regulate their positive emotions (up-regulate condition) in reaction to positive film clips. We not only tested the relation between a higher emotional reactitivity towards positive stimuli and higher well-being (e.g., Carl et al., 2014), but we also hypothesized that specifically greater up-regulation success is related to higher levels of subjective well-being. To capture changes in positive affect, participants rated their momentary affect immediately before and after watching the filmclips. Such ratings are well suited for capturing changes in affective experiences, as they rely on immediate experiences. They are thereforefore – in

contrast to retrospective self-reports of feelings that relie on semantic knowledge – less biased by beliefs about the self (Robinson & Clore, 2002a). In line with previous research, additional exploratory analyses were conducted to test the relationship between habitual emotion regulation and regulation success (McRae et al., 2012), as well as habitual up-regulation of positive emotions and subjective well-being (Bryant, 2003).

Methods

Participants and Procedure

One-hundred and eighty-three undergraduate students (48.0% women), aged between 20 and 32 years (M = 24.3, SD = 3.1 years) from Berlin, Germany, participated in this study in exchange for course credits or monetary compensation (5€/ hour). The study was approved by the ethics committee of the Humboldt-Universität zu Berlin. The study lasted a total of 5 hours, split into two experimental sessions (2.5 hours each). Each session consisted of several working memory tasks (results of which will be presented elsewhere) and an emotion regulation task. At the end of each session, participants filled in various trait questionnaires.

During the emotion regulation task, participants were instructed to regulate their emotions to sad and amusing short film clips (2-3 min). All film clips were excerpts from feature films (Amusing: *When Harry met Sally, A Fish Called Wanda,* and *Benny and Joon;* Sad: *The Champ, 21 Grams*, and *My Girl*) and have previously been shown to evoke sadness or amusement in the laboratory (Gross & Levenson, 1995; Schaefer, Nils, Sanchez, & Philippot, 2010). The film clips were split into two sequences of three films each (one sequence shown in each session; counterbalanced across participants), such that no two films of the same valence were shown consecutively. The sequence relevant for the present investigation (Figure 1A) started with an amusing-inducing film clip and the instruction to increase positive feelings (*up-regulate condition*), followed by a sadness-inducing film clip and the instruction to maintain positive emotions, and finally another amusing-inducing film clip and the instruction to simply react (*reactivity condition*). The order of the experimental conditions (i.e., order of film clips with fixedly matched instructions) was the same for each participant. Different short neutral film sequences (30 sec each) from the silent film *Die Sinfonie einer Großstadt* (English:

Symphony of a Metropolis) were shown in between the emotional film clips with the purpose to bring affect back to baseline.

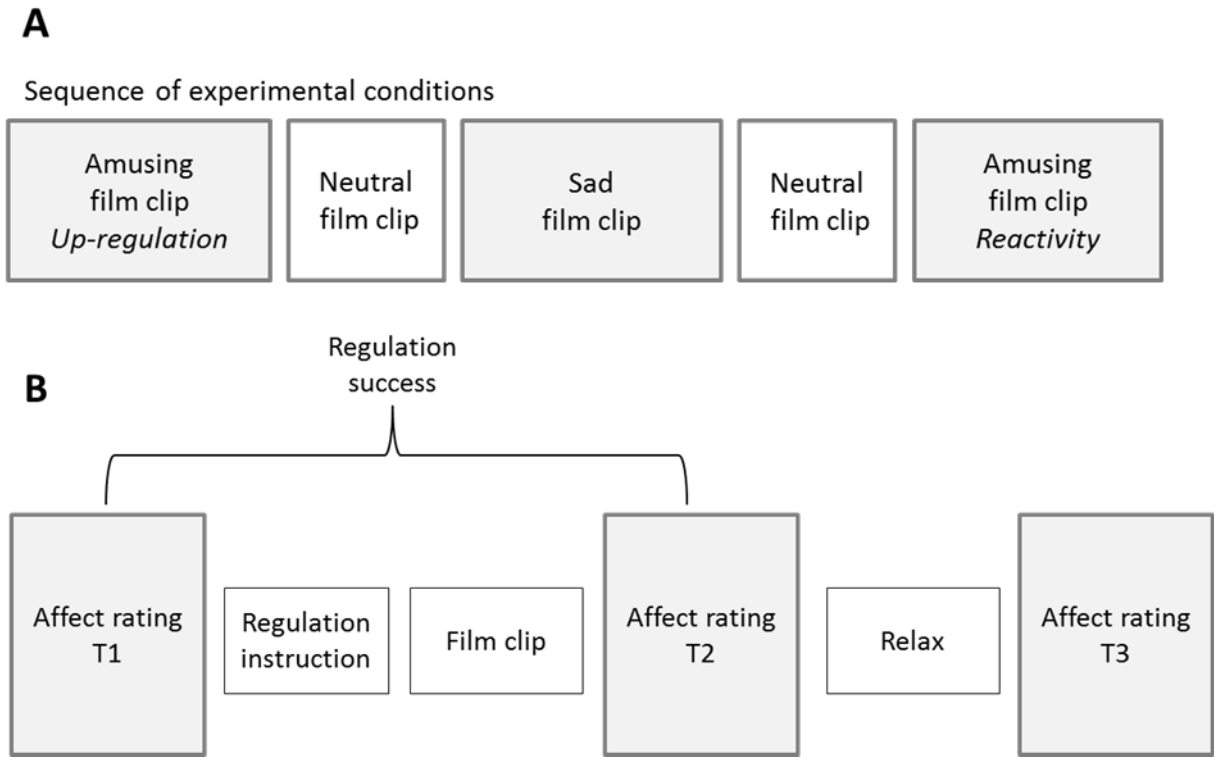

Figure 1. Schematic of the experimental design. (A) Order of conditions in each session. (B) One trial (i.e., within one condition) in the emotion regulation task.
Note. [a] counterbalanced between participants; PA = positive affect.

Before each film clip, participants first provided a baseline rating of their momentary affect, assessed via the rating (5-point Likert scale; 1 [not at all] – 5 [extreme]) of five positive (amused, cheerful, happy, good, pleased) and five negative affect items (sad, bad, unwell, depressed, unhappy), as well as one item reflecting positive arousal (excited) and one item reflecting empathy (compassionate). This affect rating was followed by the regulation instruction, the emotional film clip, and a second rating of momentary affect. After a short relaxation period (60 sec), participants were asked for a third time to rate their momentary affect (Figure 1B). Upon completion of the emotion regulation task, participants were asked to evaluate each film clip, by indicating on a 5-point Likert scale (1 [not at all] – 5 [very much]), how much each affect item (same affect items as in the

momentary affect rating) provides a good description of the film clip. Given our interest in reactivity to positive stimuli and up-regulation, we only considered the respective conditions (i.e. up-regulation and reactivity condition) as well as the first two ratings of momentary positive affect in the analyses.

Measures

Positive affect: An overall score of positive affect (PA) was calculated for each affect rating, that is, before (T1) and after (T2) each film clip. This was done by aggregating over all positive affect items (Reliability at T1: Cronbach's $\alpha = .92$).

Subjective well-being: Subjective well-being was assessed with the Satisfaction with Life Scale (SWL; answering scale: 1 [completely disagree] – 7 [completely agree]; Diener, Emmons, Larsen, & Griffin, 1985), measuring the cognitive component of subjective well-being, the positive subscale of the Positive and Negative Affect Schedule (PANAS; answering scale: 1 [very little to never] – 5 [extremely]; Watson, Clark, & Tellegen, 1988), measuring the affective component of subjective well-being, and the WHO-5 Scale (answering scale: 1 [at no time] - 5 [all the time]; World Health Organization, 1998), measuring overall subjective well-being. We used an overall score of subjective well-being (the mean across all z-standardized scores, Cronbach's $\alpha = .72$) for analyses.

Habitual emotion regulation: Habitual up-regulation of positive emotions was assessed with the subscale of the Cognitive Emotion Regulation Questionnaire (CERQ; Garnefski, Kraaij, & Spinhoven, 2001) that measures adaptive emotion regulation startegies [answering scale: 1 (never) – 5 (always)], the reappraisal subscale of the Emotion Regulation Questionnaire (ERQ; Gross & John, 2003) that measures cognitive reappraisal [answering scale: 1 (does not apply at all) – 5 (applies completely)], and a shortened version of the Emotion Regulation Profile-Revised (ERP-R; Nelis, Quoidbach, Hansenne, & Mikolajczak, 2011). The ERP-R measures the hypothetical regulation of positive emotions: Participants indicate for different scenarios which strategy they were most likely to engage in. We only considered four scenarios targeting positive emotions and only considered adaptive strategy endorsement. Cronbach's α for the different emotion regulation scales was .88, .78 and .93, respectively.

Analyses

Up-regulation success: To test whether participants reacted to the amusing film clips with an increase in positive affect and successfully up-regulated their emotions during the task, we conducted a repeated measures analysis of variance (ANOVA) with PA as the dependent variable and time (T1 and T2) and condition (up-regulation and reactivity condition) as within-subject factors.

Up-regulation success and subjective well-being: To test whether people with higher levels of subjective well-being have enhanced levels of reactivity to positive film clips and are particularly successful when up-regulating their positive affect in response to positive filmclips, we conducted the same repeated measures ANOVA as just described and additionally included overall subjective well-being as a covariate. Additionally, we calculated Pearson correlations between overall subjective well-being, reactivity, and regulation success, calculated as the change in PA from before to after each film clip (i.e., T2-T1).

Habitual emotion regulation and subjective well-being: Pearson correlations were conducted between habitual emotion regulation indices and overall subjective well-being.

Habitual emotion regulation, reactivity and up-regulation success: Pearson correlations were conducted between habitual emotion regulation indices, reactivity, and regulation success were calculated as the change in PA from before to after each film clip (i.e., T2-T1).

Results

Descriptive statistics of all variables can be found in Table 1.

Emotion regulation success: Across both conditions, there was an increase in PA from before to after the film clip, as indicated by a significant main effect of time, $F(1, 182) = 417.6$, $p < .001$. Moreover, participants had higher levels of PA in the up-regulation condition, as indicated by a significant main effect of condition, $F(1, 182) = 129.89$, $p < .001$ (Figure 2). The was no significant interaction between condition (reactivity/up-regulation) and time (T1/T2), $F(1, 182) = 0.025$, $p = .874$, indicating that the change in PA from before and after the film clip did not differ between conditions. Together, positive film clips elicited positive reactions, as indicated by increases in positive affect. Regulatory efforts towards enhanced positive affect, as instructed in the up-regulation condition, did

not seem to have resulted in further increases in positive affect, most likely due to the different baselines between the two conditions.

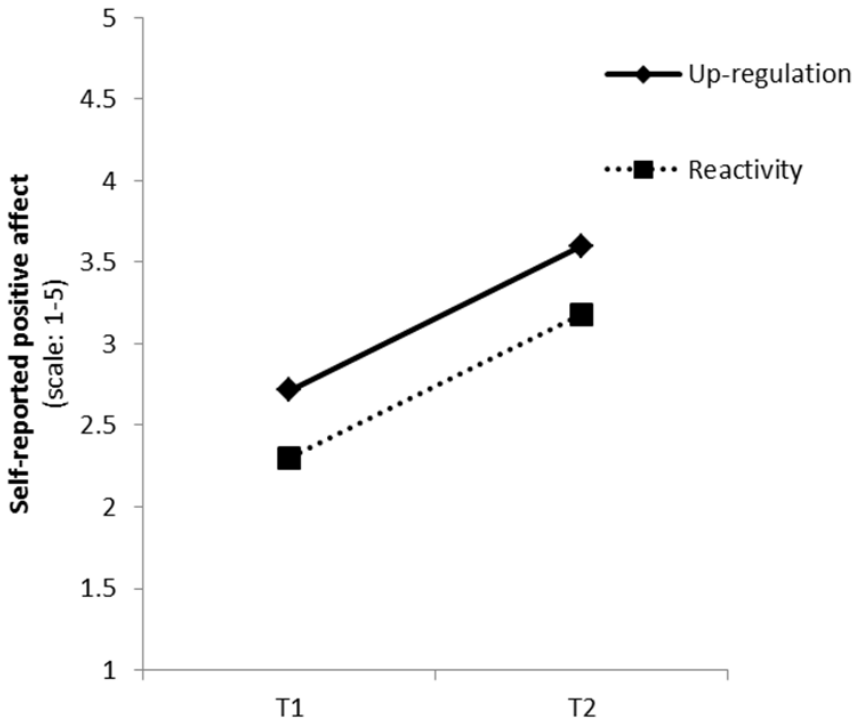

Figure 2. Self-reported positive affect (PA) for each condition. Participants had higher levels of PA in the up-regulation condition, both before (T1) and after the film clip (T2; significant main effect of condition, $F(1, 182) = 129.89$, $p < .001$).

Table 1.
Descriptive Statistics of all Variables in this Study.

Variable	*M*	*SD*
Subjective well-being		
SWL	24.41	5.49
PANAS positive	33.93	6.09
WHO-5	20.31	4.31
Trait emotion regulation		
CERQ adaptive	64.18	2.38
ERP-R positive	4.32	3.59
ERQ Reappraisal	25.91	6.03
Positive affect		
Up-regulation		

T1	2.72	0.75
T2	3.60	0.73
Reactivity		
T1	2.30	0.78
T2	3.18	0.85

Note. SWL = Satisfaction with Life Scale; PANAS = Positive and Negative Affect Schedule; WHO-5 = WHO (Five) Well-being Index; CERQ = Cognitive Emotion Regulation Questionnaire; ERP-R = Emotion Regulation Profile Revised; ERQ = Emotion Regulation Questionnaire; T1 = Affect rating before the film clip; T2 = Affect rating after the film clip

This result was followed up with a paired-sample t-test to test whether one of the two film clips of the different conditions was perceived as more positive. If the film clip of the watch condition had been perceived as more positive, this could potentially have explained why we did not find relatively stronger increases in PA in the up-regulation condition. The result was, however, that participants perceived the film clip in the up-regulation condition as more positive, compared to the film clip in the reactivity condition, $t(182) = 4.533$, $p < .001$.

Subjective well-being and up-regulation of positive emotions: There was no significant 3-way-interaction between condition, time and subjective well-being, $F(1, 181) = 0.21$, $p = .651$; Table 2). Thus, participants with higher subjective well-being did not have a higher increase in PA when up-regulating positive emotions (i.e., they did not show greater up-regulation success), compared to simply reacting to the positive film clips. Similarly, there was no significant interaction between time and subjective well-being, indicating that participants with higher subjective well-being did not have higher increases in PA across the two conditions. Separate ANCOVAs for the two conditions confirmed that well-being did not interact with time in either condition. That is, well-being did not matter for reactivity or up-regulation success in this study.

Table 2.
Results from the Repeated Measures ANOVA with PA as a Dependent Variable.

Source of Variation	Sum of squares	df	Mean Square	*F*	Eta^2
Within-Subjects					
Condition	31.98	1	31.98	129.23**	.42
Condition x Subjective well-being	.02	1	.02	.08	.00
Time	142.88	1	142.88	415.73**	.70

Time x Subjective well-being	.06	1	.06	.19	.001
Condition x Time	.004	1	.004	.03	.00
Condition x Time x Subjective well-being	.04	1	.04	.21	.001

Note. PA = positive affect. ** $p < .001$, * $p < .05$.

Habitual emotion regulation and subjective well-being: There was a significant positive correlation between subjective well-being and the adaptive emotion regulation subscale of the CERQ ($r = .52$, $p < .001$) and the reappraisal subscale of the ERQ ($r = .34$, $p < .001$), but not the positive subscale of the ERP-R ($r = .07$, $p = .35$; Table 3).

Habitual emotion regulation and up-regulation success: There was a marginally significant positive correlation between up-regulation success (i.e., the change score from the up-regulation condition) and the ERP-R ($r = .15$, $p = .05$). All other correlations did not reach significance (Table 3), indicating that the more conventional measures were not associated with our performance-based indicators of reactivity and up-regulation success.

Table 3.
Pearson Correlations Between Habitual Emotion Regulation, Regulation Success and Subjective Well-Being

	Overall well-being	Habitual emotion regulation		
		CERQ adaptive	ERQ reappraisal	ERP-R positive
Habitual emotion regulation				
CERQ adaptive	.52**			
ERQ adaptive	.34**	.40**		
ERP-R positive	.07	.03	.02	
Up-regulation success	.01	-.11	-.02	.15*
Reactivity	.04	.02	.12	.11

Note. Up-regulation success = change in PA from T1 to T2 in the up-regulation condition; Reactivity = change in PA from T1 to T2 in the reactivity condition.
** $p < .001$, * $p < .05$.

Discussion

The study investigated the relationship between the successful up-regulation of positive emotions (indexed by a performance-based measure of emotion regulation) and subjective well-being.

More specifically, we tested the hypothesis that greater increases in positive affect when up-regulating positive emotions (i.e., greater up-regulation success) are related to higher levels of subjective well-being. We expected this effect, over and above that of subjective well-being on simply reacting to positive film clips.

During the emotion regulation task, participants reacted to the positive film clips, as indicated by increases in their positive affect. Interestingly, participants did not have particularly stronger increases in positive affect when instructed to up-regulate their emotions, compared to simply reacting to a positive film clip. Moreover, our hypothesis of a relation between greater up-regulation success and higher subjective well-being was not supported. Similarly, we did not find that higher subjective well-being was related to greater positive reactivity to positive stimuli. Finally, we found a somewhat mixed pattern regarding habitual emotion regulation. While two indices of habitual emotion regulation (the adaptive subscale of the CERQ and the reappraisal subscale of the ERQ) were not significantly related to regulation success but positively linked to subjective well-being, the third indicator (positive subscale of the ERP-R) was marginally positively related to regulation success, but not subjective well-being.

No Difference in Change in Positive Affect Between Conditions

The fact that we did not find a difference in the increase in positive affect between our two conditions seems to suggest at first that either no regulation occurred or that regulatory efforts did not lead to further increases in affect, compared to simply reacting to the positive film clip. Yet, given previous studies with similar paradigms that did report successful up-regulation of positive emotions (e.g., Giuliani et al., 2008) it seems unlikely that no regulation occurred in our study or that regulation was not successful. Instead, what may have happened is the following. Due to the inclusion of sad film clips and the experimental design (i.e., fixed order of conditions); participants seem to have experienced a drop in momentary affect before the reactivity condition from which they had not fully recovered. That is, baseline positive affect was much higher in the up-regulation condition than in the reactivity condition. Thus, it could be that participants implicitly (e.g., through a greater reaction or implicit up-regulation) or explicitly (e.g., through deliberate up-regulation of positive emotions)

maximized their positive affect in the reactivity condition without the instruction to do so. This speculation is further supported by the fact that participants perceived the film clip in the reactivity condition as less positive. Thus, if participants had simply reacted to the film clip in the reactivity condition, increases in positive should have been lower than in the regulation condition. Together, participants may have used the amusing film clip in the reactivity condition as a means to brighten their relatively sad mood. This idea is in line with recent research that emphasizes the role of positive emotions as a buffer against negative and distressing experiences. Both, reduced positive reactivity to daily stressors (i.e., less decreasses in positive affect in response to a negative event; Sin, Graham-Engeland, Ong, & Almeida, 2015), as well as the deliberate enhancement of positive affect in negative contexts (McRae & Mauss, 2016; Tugade & Fredrickson, 2007) have been related to markers of well-being and resilience.

This interpretation of the present findings needs to remain speculative. As there was no significant difference in the increase in positive affect between the two conditions, it is not possible to conclude whether either of the observed changes reflects an unmodulated reactivity or deliberate up-regulatory efforts.

Subjective Well-Being and Successful Up-Regulation of Positive Emotions

Against our expectation, we neither found that higher levels of subjective well-being were particularly strongly related to higher upregulation success (particularly strong increases in positive affect in the up-regulation condition), nor did we find that higher levels of well-being were related to greater positive reactions (higher increases in positive affect in the reactivity condition). This finding seems surprising, given previous studies that have shown a positive link between habitual up-regulation of positive emotions and subjective well-being (Bryant, 2003; Quoidbach et al., 2010) and studies showing that well-being is associated with enhanced reactions to positive stimuli (Bylsma et al., 2008; Grosse Rueschkamp et al., 2018). However, we did find a positive association between habitual emotion regulation and subjective well-being, whereas these same indicators of habitual emotion regulation were not associated with up-regulation success. Thus, these findings may suggest that people who report to regulate more frequently (as measured through questionnaires tapping into

habitual emotion regulation) not necessarily do so more successfully. Moreover, only the former seems to be characteristic of people with higher subjective well-being, contradicting theoretical work that stresses the capacity to up-regulate positive experiences for high levels of subjective well-being (Bryant & Veroff, 2007) or the idea that intense positive affective experiences have benefits for well-being (Fredrickson, 2001). This finding is of importance given the various studies that treat habitual emotion regulation as an indicator for the capacity to up-regulate positive emotions.

One possible explanation for these divergent findings regarding the relationship with subjective well-being is that different types of measures were used as indicators for habitual emotion regulation and up-regulation success. Habitual emotion regulation, just as subjective well-being, was measured via self-reports of global behavioral tendencies. Both measurements therefore likely include similar belief-based biases (e.g. a person with a positive self-belief will likely rate his overall well-being as more positive, but also his ability to up-regulate positive experiences as higher; Robinson & Clore, 2002). The influence of these biases, however, declines when reports of momentary affect are used. Moreover, the indicators of emotion regulation success that were derived from these self-reports (i.e., difference scores were calculated from momentary affect ratings) are beyond participants' introspection or evaluations. Hence, the shared method variance between these indicators of up-regulation success and levels of subjective well-being should be minimized.

One indicator of habitual emotion regulation (the shortened version of the ERP-R) seems to fall out of this pattern. In contrast to the other scales (which capture adaptive emotion regulation more generally), this trait questionnaire is specific to positive emotions and, additionally, assesses emotion regulation via vignettes (Nelis et al., 2011). These require participants to indicate their regulation behavior in very specific situations (resembling actual experiences), instead of making more global evaluations thereof. Therefore, retrospective biases might be less of concern, potentially explaining the marginally significant correlation with up-regulation success in our study. Nevertheless, it is important to point out that this correlation was only small and requires being replicated.

Limitations and Implications for Future Research

The present study has several limitations. Most importantly and as already mentioned above – there was a difference in the level of positive affect between the two conditions before the two positive film clips, which may have resulted from our specific experimental design. Thus, it could not be determined how these different baselines might have influenced the degree of reactivity or regulation behavior in either condition and therefore limits the interpretability of the present findings. An important goal for future studies would be to test the present hypotheses with different experimental designs (e.g., no simultaneous use of negative stimuli within the same emotion regulation task).

Another limitation is that instructions were matched with the film clips. Thus, it was not possible to fully control for confounding factors, such as differences in the evaluation of the film clips. To overcome these limitations, future research should test up-regulation success with a greater number of trials as well as randomized instructions to eliminate the possibility of such effects.

Conclusion

Taken together, we found that participants had significant increases in positive affect in response to the positive film clips, however not greater increases when instructed to up-regulate their positive emotions, compared to simply reacting to the film clips. Furthermore, while we found, in line with previous studies, a positive association between emotional reactivity and subjective well-being as well as habitual emotion regulation and subjective well-being, no such link was evident between our performance-based indicators of reactivity or up-regulation success and subjective well-being. Furthermore, up-regulation success in the laboratory task was not or only very weakly related to habitual emotion regulation. These results point towards the differences between performance-based indicators and self-report measures of emotion regulation, and challenge the idea that a greater capacity to up-regulate positive emotions is beneficial for subjective well-being. These findings represent a first step into integrating different methods in the study of positive emotion regulation.

8 Paper II

Neural Correlates of Up-Regulating Positive Emotions in fMRI and Their Link to Affect in Daily Life

Johanna M. Grosse Rueschkamp[1,4], Annette Brose[1], Arno Villringer[2,3,4],

& Michael Gaebler[2,4]

[1] Humboldt-Universität zu Berlin, Berlin, Germany

[2] MindBrainBody Institute at the Berlin School of Mind and Brain, Humboldt-Universität zu Berlin, Berlin, Germany

[3] Stroke Center Berlin and NeuroCure Cluster of Excellence, Charité – Universitätsmedizin Berlin, Berlin, Germany

[4] Department of Neurology, Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany

This article has been submitted for publication in an academic journal and is currently under review.

Acknowledgments

We thank Jennifer Spiegel and Sandy Hannibal for their help acquiring the data, Deniz Kumral for her assistance in quality assessment of the MRI data, Karsten Mueller for methodological advice, and Lorenz Deserno for helpful comments on the manuscript. Johanna M. Grosse Rueschkamp is a pre-doctoral fellow of the International Max Planck Research School on the Life Course (LIFE, www.imprs-life.mpg.de).

Correspondence

Johanna Grosse Rueschkamp, Humboldt-Universität zu Berlin, Germany, Institute of Psychology, Emmy Noether Independent Junior Research Group "Adaptation to Major Life Events", Unter den Linden 6, 10099 Berlin, Germany. Email: johanna.grosserueschkamp@hu-berlin.de

Abstract

Emotion regulation is typically used to down-regulate negative or up-regulate positive emotions. While there is considerable evidence for the neural correlates of the former, less is known about the neural correlates of the latter – and how they are associated with emotion regulation and affect in daily life. From 63 healthy young participants (22±1.6 years, 30 female), fMRI data was acquired while they up-regulated their emotions to positive and neutral images or passively watched them. From the same participants, daily affect and emotion regulation behavior were measured using experience-sampling over 10 days. Focusing on the ventral striatum (VS), which was previously associated with positive affective processing, we found increased activation during the up-regulation to both positive and neutral images. VS activation for the former positively correlated with between- and within-person differences in self-reported affect during fMRI but was not significantly associated with up-regulation in daily life. However, participants with lower daily affect showed a stronger association between changes in affect and activation in emotion-related (medial frontal and subcortical) regions – including the VS. These results support the involvement of the VS in up-regulating positive emotions and suggest a neurobehavioral link between emotion-related brain activation and emotions in daily life.

Keywords: positive emotions, experience-sampling, ventral striatum, affect, up-regulation

Our emotional experiences are characterized by ups and downs. While these changes depend on situations we encounter, we also influence how we feel through deliberately up- or down-regulating our emotions. There are different motivations to do so, but, in general, people are pro-hedonically motivated, that is, they want to maintain or increase their positive and decrease their negative emotions (Riediger et al., 2009). Previous neuroimaging studies have mainly focused on the down-regulation of negative emotions and identified brain regions or networks supporting this type of regulation: Most often, "cognitive control" regions in prefrontal and parietal cortices have been shown to modulate subcortical regions involved in emotional responding (e.g., amygdala; Buhle et al., 2014). However, people can also pursue pro-hedonic goals by enhancing positive emotions. While behavioral studies in the laboratory (Giuliani et al., 2008) and in daily life (Jose et al., 2012) found that up-regulating positive emotions can enhance momentary levels of affect, less is known about the brain regions underlying this form of emotion regulation and the heightened experience of affect.

One of the brain structures suggested to be involved in – particularly positive – affective processing is the ventral striatum (VS). The VS has been implicated specifically in reward-related behavior (Kringelbach & Berridge, 2009; Schultz, Dayan, & Montague, 1997) and more generally in positive emotional responding, for example, to pleasant music (Blood & Zatorre, 2001), smiling faces (Vrtička et al., 2008), or positive images (Sabatinelli et al., 2007). Furthermore, VS activity can be modulated through emotion regulation, for example by cognitive reappraisal, which can increase positive emotions in negative contexts (Doré et al., 2017). Thus, to the extent that the up-regulation of positive emotions successfully enhances positive affective experiences, it should also modulate activity in the VS.

Indeed, the few existing fMRI studies that examined the up-regulation of positive emotions reported increased activation in the VS – along with activation in medial and lateral prefrontal areas (similar to the down-regulation of negative emotion), the temporal lobe, and the anterior cingulate (Greening et al., 2014; Kim & Hamann, 2007; Li et al., 2018; Moutsiana et al., 2014; Vrticka et al., 2011). In one of these studies, increased VS activity was related to behavioral measures of regulation success, that is, higher positive affect during up-regulating compared to just watching positive stimuli

(Greening et al., 2014). However, several aspects of the role of the VS during the up-regulation of positive emotions remain unknown:

First, previous studies that found increased activation in the VS during the up-regulation of positive emotions used a passive baseline condition of "naturally" viewing positive stimuli as a control condition. However, to disentangle neural responses of affect-related up-regulation from more general regulatory efforts, an "active" control condition is needed; such as the up-regulation to neutral stimuli, which are thought to induce minimal affect (Gasper, 2018). Based on reports that the VS supports the heightened experience of positive affect during emotion regulation (e.g., Doré et al., 2017), we hypothesized stronger VS activation during the up-regulation to positive than to neutral stimuli, as the latter should not lead to changes in momentary affect.

Second, while activation in the VS has been related to between-person differences in the ability to up-regulate positive emotions (i.e., individuals with more activation have higher positive affect; Greening et al., 2014), it is important to also consider variability *within* individuals. A relation between VS activity and within-person changes in affect would indicate that, in addition to being persistently activated across contexts, the VS also reflects more subtle moment-to-moment changes in affect during the up-regulation of positive emotions. Such dynamic changes in affective states have also been associated with reward-related learning processes in the VS (Eldar, Rutledge, Dolan, & Niv, 2016; Rutledge et al., 2014). For example, exaggerated reward expectations during heightened positive affective states lead to decreases in positive affect. Lower affective states then facilitate increases in positive affective experiences through adjusted reward expectations (Eldar & Niv, 2015; Eldar et al., 2016). Combined with the relation between VS activity and differences in affect during the up-regulation of positive emotions (e.g., Greening, 2014), we hypothesized that activation in the VS also reflects within-person changes in affect during the up-regulation of positive emotions. Understanding the neural responses that support these brief changes in affect is particularly relevant considering the unpredictability of everyday-life situations. Ever-changing contexts and an individual's interaction with them naturally result in varying regulatory efforts and varying affective states.

To test an association between brain activation and moment-to-moment changes in affect – and to determine its generalizability (Araújo et al., 2007) – it is beneficial to (also) test individuals in their "natural habitat". Studies that combined laboratory and daily-life measures found, for example, that reward-related VS activity was positively related to positive affect during a smartphone game in daily life (Heller et al., 2015). Assuming a similarity of behaviour in- and outside the laboratory, we expected that increased VS activity during emotion regulation in the fMRI also relates to changes in momentary affect when up-regulating positive emotions in daily life.

Taken together, in the present study, we investigated the neurobehavioral associations of the up-regulation of positive emotions during fMRI and in daily life. First, a standard emotion regulation paradigm was used to measure neural and behavioral responses while participants were instructed to up-regulate their affect to positive and neutral images during fMRI – compared to passively watching them. Given its above mentioned involvement in positive affective processing, the present study focused on the role of the VS for the heightened experience of affect during the up-regulation of positive emotions. We tested three hypotheses: (1) The VS is recruited more strongly when up-regulating to positive images compared to just watching them and to up-regulating to neutral images; (2) higher VS activation is related to higher between-person levels of affect during up-regulation; (3) higher VS activation is related to higher within-person changes in affect during up-regulation (i.e., on a trial-by-trial basis).

Second, participants completed an additional 10 days of smartphone-based experience-sampling in their daily lives, during which they reported their momentary affect and degree of regulating positive emotions. Given the small empirical basis with a similar approach, we explored whether stronger activation in the VS during instructed up-regulation in the laboratory is related to higher changes in momentary affect when up-regulating in daily life.

Materials and Methods

Participants

Seventy-seven healthy participants between 18 and 25 years (M=22, SD=1.6, 39 women) were recruited through mailing lists and online ads. Exclusion criteria were current psychiatric or

neurological disorders, an above normal body mass index (18.5 to 25 kg/m^2), and standard MRI contraindications (e.g., metallic implants). Data from two participants were excluded due to technical issues (wrong MRI sequence parameters and crashing task presentation) and two participants decided to terminate their participation. After a more detailed screening during the testing session, an additional ten participants were excluded because of a history of neurological or psychiatric diagnoses. Hence, 63 participants (*M*=22, *SD*=1.6, 30 women) entered the analyses.

Procedure

The experiment comprised two phases, an fMRI and an experience-sampling method (ESM) phase, the order of which was counterbalanced across participants (49% fMRI first). During the ESM introductory session, participants received smartphones and completed trait questionnaires (not relevant for the current research question; Supplement 1.1). During fMRI, an emotion regulation task and a reward-learning task (the results of which will be presented elsewhere) were performed. Both tasks were practiced beforehand outside the scanner. Participant reimbursement ranged from 44.50 to 90 Euros, depending on the performance in the reward learning task and the number of completed ESM measurement occasions. The study was approved by the ethics committee of the medical faculty at the University of Leipzig.

Emotion regulation task in the MRI

Forty positive (Pos; valence: *M*=7.09, *SD*=0.34; arousal: *M*=4.59, *SD*=0.72) and 40 neutral images (Neu; valence: *M*=5.29, *SD*=0.17; arousal: *M*=3.15, *SD*=0.40) were chosen as stimuli from the Emotional Picture Set (EmoPicS; Wessa et al., 2010) based on the normative ratings (9-point Self-Assessment Manikins: 1=sad/calm, 9=happy/excited) and between conditions matched for number of persons depicted, social interactions, close-up images and eye contact. Participants were instructed to either up-regulate their emotions ("deliberately intensify the emotions you are experiencing"; Up) or to passively watch ("experience the emotions naturally as they come and go"; Watch) indicated by the cue words "Enhance" or "Watch" (for exact wording in German, Supplement 1.2). No specific emotion regulation strategy was instructed with the aim to maximize the comparability with the assessment in daily life, where people report using several emotion regulation strategies (Heiy &

Cheavens, 2014). Each of the four experimental conditions (PosUp, PosWatch, NeuUp, NeuWatch) had 20 trials, split into two runs of 40 trials each. For each participant, images were randomly assigned to the four conditions and the trial order was pseudo-randomized with the constraint of maximally three consecutive trials from the same condition. Before and after each image, participants rated their current affect ("At the moment I feel") on a scale from -3 ("bad") to +3 ("good"; see Figure 1).

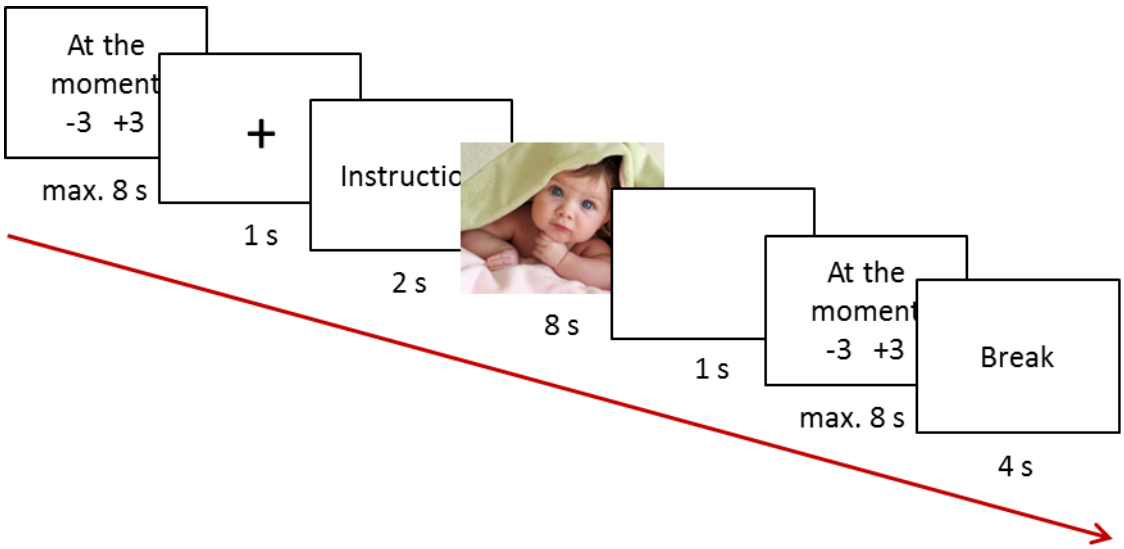

Figure 1. Schematic of one trial in the emotion regulation task: (i) fixation cross, (ii) pre-image affect rating (trial continued when answer was given), (iii) instruction cue word ("Enhance" or "Watch"), (iv) inter-stimulus interval, (v) post-image affect rating (trial continued when answer was given), and (vi) short break.

Experience-sampling in daily life

During the 10-day ESM phase (two periods of five days, separated by a two-day break), participants answered questions on a smartphone (Huawei Ascend G330), which beeped six times per day at pseudo-random time points (between 45 and 195 min apart) within 12 hours. On average, participants answered on 54.5 beep-induced occasions (*SD*=10.2). At each occasion, we assessed momentary affect ("At the moment I feel", scale: -3 ("bad") to +3 ("good")) and the degree of emotion regulation ("I tried to intensify my pleasant feelings"; scale: 0 ("not at all") to +6 ("very much")) since

the last occasion. In the following, "momentary affect" refers to ratings during the ESM phase and "self-reported affect" refers to ratings during the fMRI task.

MRI acquisition and processing

MRI was performed at the Berlin Center for Advanced Neuroimaging using a 3-T Siemens Tim Trio MRI (Siemens, Erlangen, Germany) with a standard 12-channel head coil. T1-weighted images were acquired with an MPRAGE pulse sequence (TR=1900 ms, TE=2.52 ms, FOV=256 mm, 192 slices, flip angle=9°, voxel size=1 mm isotropic). Functional images were acquired using a T2*-weighted gradient-echo echo-planar imaging (EPI) sequence (TR=2090 ms, TE=22 ms, flip angle=90°, FOV=192 mm, voxel size=3 mm isotropic). Forty slices of 2.5 mm (0.5 mm gap) were obtained in interleaved order parallel to the anterior-posterior commissure (AC-PC) line. A field map (TR=438, TE_1=5.19 ms, TE_2=7.65 ms, flip angle=60°, FOV=192 mm) was acquired (before the EPI sequence) for distortion correction. The experiment was presented on an MR-compatible screen (NordicNeuroLab, Bergen, Norway) using OpenSesame 3.0.6 (Mathôt, Schreij, & Theeuwes, 2012). MR images were processed and analyzed using SPM12 (http://www.fil.ion.ucl.ac.uk/spm/software/spm12/). First, four dummy scans, acquired at the beginning of each run, were excluded. FMRI preprocessing consisted of slice time correction, realignment to the mean EPI, co-registration of the T1-weighted image to the mean EPI, segmentation into three tissue classes (GM, WM, CSF), and normalization to MNI space (3 mm isotropic voxels) with the IXI555 template (from 555 healthy subjects; www.brain-development.org) plus spatial smoothing (with an 8-mm full-width-at-half-maximum Gaussian kernel) using DARTEL. No participant had to be excluded due to head movement (cut-off: >0.3 mm of mean frame displacement; Power, Barnes, Snyder, Schlaggar, & Petersen, 2012; Power, Schlaggar, & Petersen, 2015).

Statistical Analyses

Behavioral analyses. As a manipulation check, we first tested successful emotion regulation during fMRI and in daily life using linear-mixed modeling. Successful up-regulation of positive emotions during fMRI (i.e., higher levels of self-reported affect during up-regulation to positive images compared to just watching them and to up-regulation to neutral images) was determined using

the post-image affect rating as the outcome variable with valence (Pos, Neu), instruction (Up, Watch), and their interaction as predictors. Follow-up analyses were conducted on positive and neutral trials separately, only with instruction as a predictor. To determine trial-wise regulation success, the change in affect for each trial was calculated as the difference between the post- and pre-image self-reported affect. The pre-image rating provides a trial-specific baseline, reflecting within-person changes in affect more directly (Augustine & Hemenover, 2009).

To test successful emotion regulation in daily life, momentary affect at each occasion was used as the outcome variable and the degree of emotion regulation as a predictor. To get a better proxy of the *change* in momentary affect, affect at the previous occasion was included as a lagged score as an additional predictor. Measures from these analyses were used for hypothesis-specific tests of a relation between neural activation and differences in affect (see below).

fMRI – first and second-level analyses. At the first level, a general linear model (GLM) was specified for each participant to model the BOLD signal for each condition (using a canonical hemodynamic response function). The six motion parameters were entered as regressors of no interest. At the second (i.e., group) level, random effects analysis was performed. According to our hypotheses, region-of-interest (ROI) analyses of the VS were conducted using a binarized mask based on coordinates from 9 reward-related studies (Rothkirch, Schmack, Deserno, Darmohray, & Sterzer, 2014 for more details) and family-wise error (FWE) corrected for multiple comparisons at $p<.05$.

VS ROI analyses were complemented by exploratory whole-brain analyses, for which cluster-extent based thresholding was used with $p<.001$ (uncorrected) at the voxel- and $p<.05$ (FWE-corrected) at the cluster-level. For each contrast, cluster extent thresholds k (ranging from 92 to 113 voxels) were estimated with the tool "SPM Cluster Size Threshold" (version date: 12 Jan 2016; https://github.com/CyclotronResearchCentre/SPM_ClusterSizeThreshold).

To test for an association between dynamic within-person changes in affect (i.e., trial-by-trial changes in affect) and BOLD signal, parametric analyses were conducted: changes in affect were included as a parametric regressor at the first and a one-sample t-test was performed at the level.

All resulting t-maps are available on NeuroVault (Gorgolewski et al., 2015): https://neurovault.org/collections/MAZDXCZW/. To psychologically interpret the results of the exploratory whole-brain analysis in a data-driven way, the respective t-maps were compared (using NeuroVault's *decode* function) with terms of the online database Neurosynth, which contains activations and associated (psychological, anatomical) labels from 14,371 studies (Yarkoni, Poldrack, Nichols, Van Essen, & Wager, 2011).

All (Pearson) correlations of the link between behavioral and neural measures were outlier-corrected (3 *SD*) and to determine statistical significance, a (two-sided) α-level of .05 was used.

VS activity during up-regulation. To examine whether the VS is particularly activated during the up-regulation to positive images, compared to just watching them and to up-regulating neutral images, the interaction of valence and instruction ((PosUp>PosWatch)>(NeuUp>NeuWatch)), their two main effects (Pos>Neu and Up>Watch), and – given the study's focus on regulation effects – the simple effects PosUp>PosWatch and NeuUp>NeuWatch were analyzed in the VS.

Next, the hypothesis was tested that increased activation in the VS is related to higher between-person levels of affect when up-regulating positive emotions (i.e., successful up-regulation). For this, VS activity of the PosUp>PosWatch contrast was correlated with person-specific estimates of the random slopes from the linear-mixed model of the behavioral data (positive trials only), which represent average levels of affect during PosUp vs. PosWatch.

To test whether increased activation in the VS is related to greater within-person (i.e., trial-by-trial) changes in affect when up-upregulating positive emotions, we conducted a parametric analysis with changes in affect for the PosUp condition only (n=60, as three participants showed no variance in their self-reported affect in this condition).

Relating VS activity and up-regulation in daily life. As a behavioral check, laboratory measures of affect (i.e., mean self-reported affect of pre- and post-image ratings across all trials) were correlated with affect in daily life (i.e., mean momentary affect across all occasions).

To test the hypothesis that greater VS activation when instructed to up-regulate during fMRI is related to higher changes in momentary affect when up-regulating in daily life, person-specific

estimates of the random slopes were extracted from the linear-mixed model of the ESM data. These estimates (i.e., each person's change in momentary affect in relation to the degree of up-regulation), were then correlated with VS activity when up-regulating positive emotions (extracted parameter estimates from PosUp>PosWatch).

Emotion-related brain activity and its association affect in daily life. To test which brain regions – beyond the VS – are associated with changes in affect, an exploratory parametric whole-brain analysis was conducted. To increase comparability between affect measured in the laboratory and in daily life (where there are no regulation instructions and events are not categorized by valence), this analysis included changes in affect across all conditions (i.e., trials) irrespective of instruction or stimulus valence. To test the link to between-person differences affective experience in daily life (Hamann & Canli, 2004), parametric effects from all significant clusters of this analysis were extracted and correlated with the participants' mean momentary affect over all measurement occasions during the ESM phase.

Results

Behavioral results

For up-regulation during fMRI, a significant interaction (β=0.28, p<.001) and main effect of valence (β=0.76, p<.001) but no significant main effect for instruction (β=-0.04, p=0.53) were found. Follow-up analyses showed that participants successfully up-regulated to positive (β=0.24, p<.001) but not to neutral images (β=-0.04, p=0.52, Figure 2).

In daily life, participants had a greater change in momentary affect, the stronger they up-regulated their positive emotions (significant main effect of the degree of emotion regulation, β=0.29, p<.001, and affect at the previous occasion, β=0.14, p<.001; Table S2).

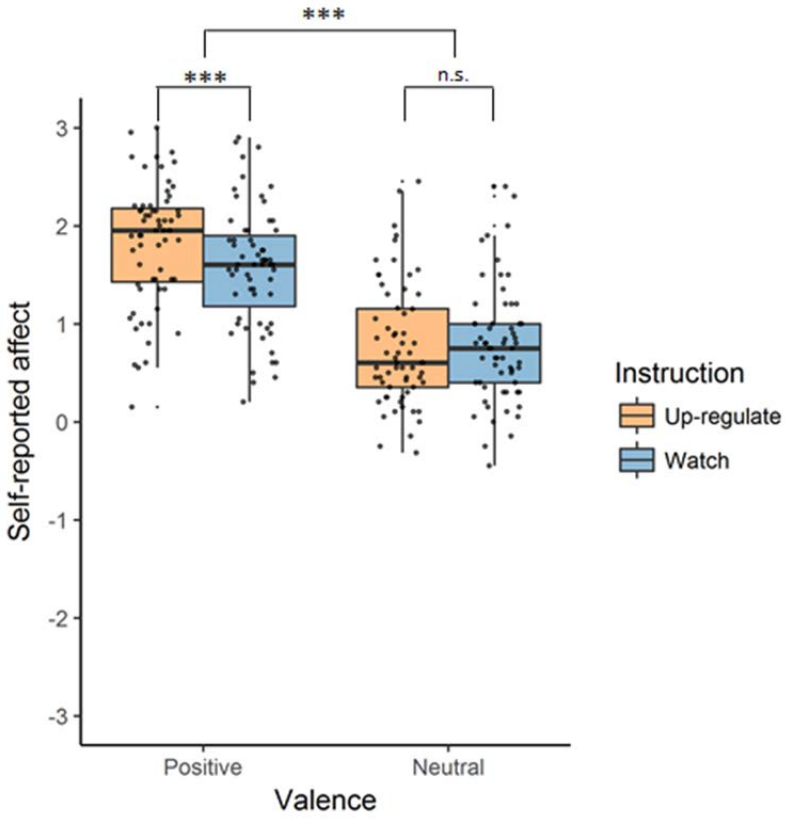

Figure 2. Self-reported affect in the emotion regulation task in the fMRI. There was a significant main effect of valence and a significant valence-by-instruction interaction effect, that is, higher self-reported affect for positive versus neutral images and for up-regulating emotions to positive images versus passively watching them. No significant difference was observed for up-regulating to neutral images versus passively watching them. Results are displayed as boxplots with median and first and third quartile. ***=p<.001; n.s.=not

fMRI results

VS activity during up-regulation. No significant voxels were found for the interaction ((PosUp>PosWatch)>(NeuUp>NeuWatch)) in the VS, which would have indicated higher activation specifically for the up-regulation to positive images, compared to passively watching them and the up-regulation of neutral images. However, in bilateral VS, main effects of valence ([-12, 3, -9], T=4.0; [18, 0, -9], T=4.6) and instruction ([-15, 0, -6], T=5.44; [15, 3, -3], T=6.47; [-9, 18, 0], T=3.13) were significant. Follow-up analyses showed significant activation in the bilateral VS for the simple effects PosUp>PosWatch ([-15, 0, -6], T=4.42; [15, 0, -6], T=4.54) and NeuUp>NeuWatch ([-18, 3, -3],

T=4.86; [15, 6, -3], T=5.92). That is, there was higher activation in the VS while up-regulating to both positive and neutral images, compared to just watching them.

VS activity and between-person differences in self-reported affect. Participants with stronger activation in the VS when up-regulating to positive images (PosUp>PosWatch) also reported higher average levels of affect (r(63)=0.28, p=.03; Figure 3A).

VS activity and within-person changes in affect. Relatively greater trial-by-trial changes in affect were related to increased engagement of the VS during the up-regulation of positive emotions, as shown by parametric increases in the left VS (PosUp condition; [-12, 6, -12], T=3.39, Figure 3B).

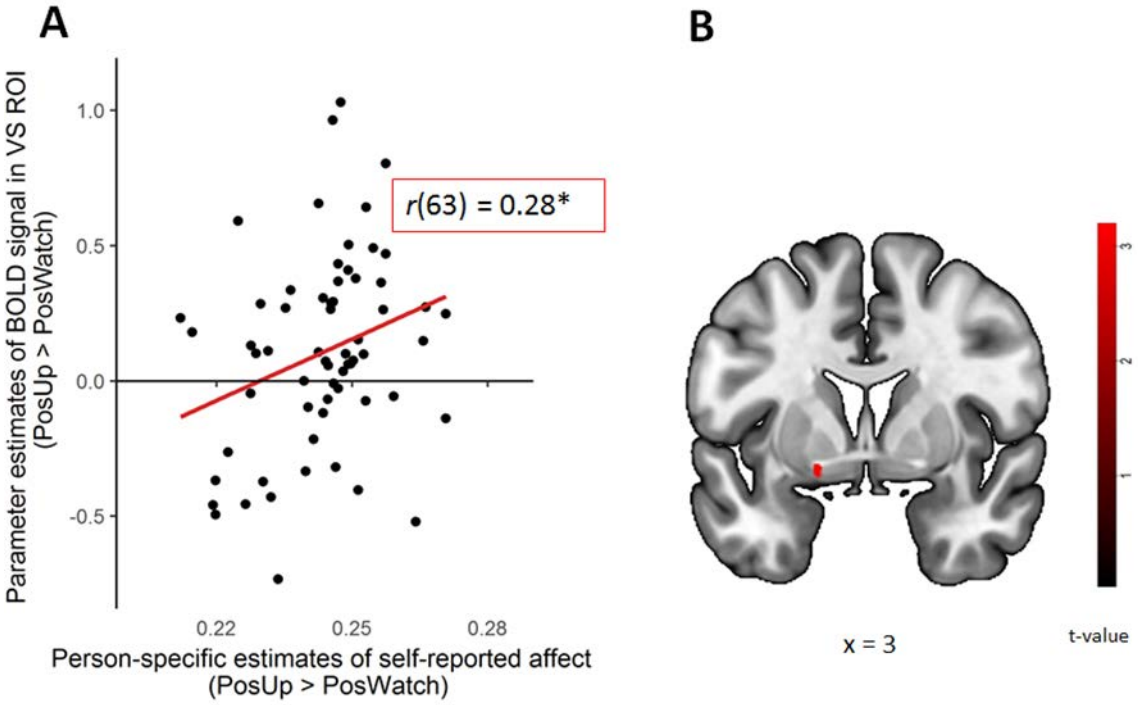

Figure 3. Association of activity in the ventral striatum (VS) with between-person (i.e., average) and within-person (i.e., trial-by-trial) differences in self-reported affect. (A) Increased VS activity (mean activation across the entire region-of-interest, ROI) was related to mean differences in self-reported affect for the up-regulation of emotions to positive images (PosUp), compared to passively watching them (PosWatch) and (B) positive association of changes in self-reported affect in the left VS during PosUp (ROI analysis: [-12, 6, -12], T=3.39, p=.05, FWE-corrected). *=p<.05

Whole-brain activity during up-regulation. In the exploratory whole-brain analysis of increased activation during the up-regulation specifically of positive images (compared to just watching them and the up-regulation to neutral images, i.e., the interaction of valence and instruction), no voxels survived multiple-comparison correction. The main effect of valence (Pos>Neu) showed widespread activation in lateral and medial temporal, frontal, and parietal cortices and in subcortical areas (Figure 4A, Table 1). The main effect of instruction (Up>Watch) yielded activation in a large cluster around the left supplementary motor area and in frontal, occipital, and cerebellar clusters (Figure 4B, Table 1). Deactivation results (i.e., the inverse contrasts) are reported in the Supplement (Table S3, section 1.3, and Figure S1).

Table 1.

Whole-brain analysis for the interaction, main effect of valence, and main effect of instruction. For corresponding brain plots, cf. Figure 4. For the inverse contrasts, cf. Table S3 and Figure S1.

Brain regions	Side	k	t	MNI coordinates		
				x	*y*	*z*
Interaction						
no significant voxels						
Positive>Neutral						
Supramarginal gyrus	R	502	7.7	66	-39	27
Supramarginal gyrus	L	318	7.23	-60	-36	30
Middle temporal gyrus	L	277	6.94	-60	-60	3
Inferior occipital	R	147	6.73	42	-84	-9
Superior frontal gyrus	L	441	5.89	-15	60	3
Precuneus	R	192	5.61	21	-42	12
Insula	L	676	5.55	-42	6	0
Rolandic operculum	R	248	5.34	51	6	6
Midcingulate gyrus	L	339	5.18	-12	-24	42

Up-regulate>Watch						
Supplementary motor area	L	10731	7.54	-9	15	69
Middle frontal gyrus	R	163	6.69	51	0	51
Calcarine sulcus	R	132	4.4	30	-72	9

Note. Clusters labeled according to the anatomical labeling (AAL) atlas (Tzourio-Mazoyer et al., 2002). Threshold: $p<.001$ (uncorrected) at the voxel- and $p<.05$ with family-wise error (FWE) correction at the cluster-level.

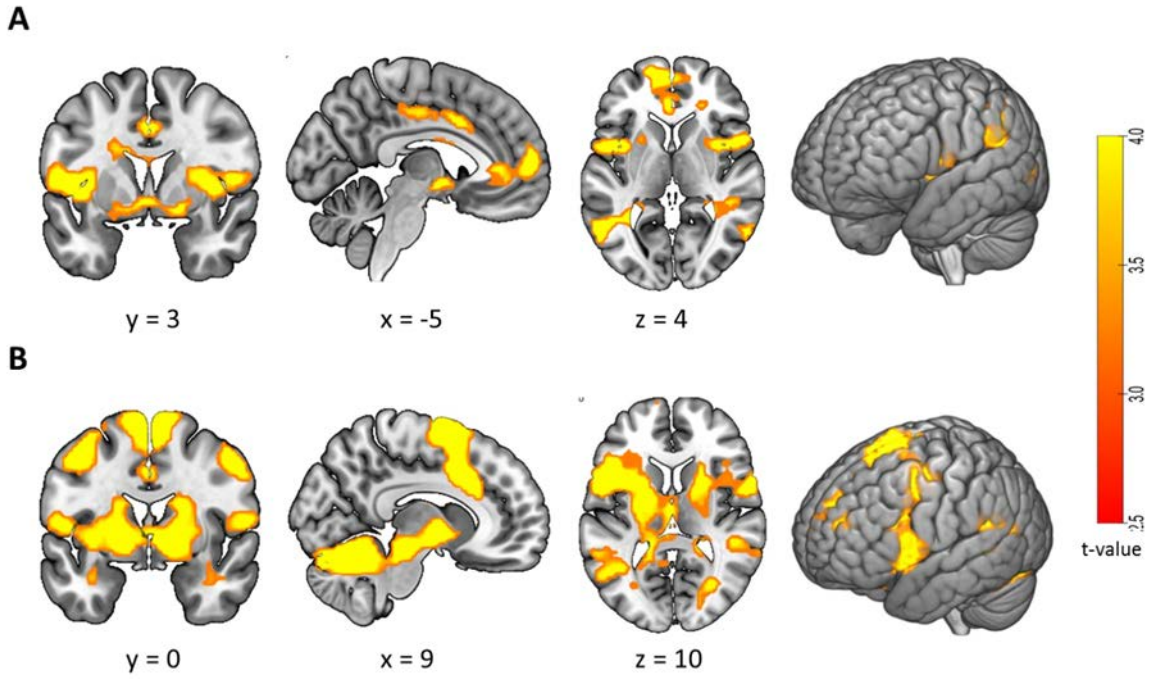

Figure 4. Brain activation in the emotion regulation task (main effects). Regions of increased activation for the (A) main effect of valence (Positive>Neutral) and (B) main effect of instruction (Up>Watch). No significant voxels were found for the interaction. Threshold: $p<.001$ (uncorrected) at the voxel- and $p<0.05$ with family-wise error (FWE) correction at the cluster-level. For details cf. Table 1. Coordinates are in MNI space

Association of whole-brain activity and changes in affect. The exploratory analysis of associations between trial-by-trial changes in affect across all conditions and activation across the whole brain showed significantly positive correlations in widespread regions around medial frontal and subcortical areas and significantly negative correlations in lateral parietal but also in medial and lateral frontal areas, extending into the left insula (Figure 5, Table 2). The Neurosynth analysis mainly

associated these regions with the anatomical labels *amygdala, hippocampus*, *ventromedial PFC* and the psychological concepts *arousal*, *emotion*, and *valence* for the positive association with changes in affect and with *inferior frontal, parietal, dorsolateral*, and *working memory, task,* and *comprehension* for the negative association with changes in self-reported affect (for a full list of the first 25 entries and their correlation values, see Table S4).

Table 2.

Whole-brain parametric analysis with changes in affect. For corresponding brain plots, cf. Figure 5.

Brain regions	Side	k	t	MNI coordinates		
				x	*y*	*z*
Increased activation						
Anterior cingulate gyrus	R	1010	5.77	18	33	3
Caudate nucleus	R	210	5.49	6	3	-6
Hippocampus	L	148	5.4	-27	-36	0
Middle occipital gyrus	L	119	4.45	-39	-60	0
Decreased activation						
Middle frontal gyrus	R	765	5.44	45	18	45
Inferior frontal gyrus, pars orbitalis	L	115	4.91	-39	18	-12
Angular gyrus	R	219	4.57	54	-57	33

Note. Clusters labeled according to the anatomical labeling (AAL) atlas (Tzourio-Mazoyer et al., 2002). Threshold: $p<.001$ (uncorrected) at the voxel- and $p<.05$ with family-wise error (FWE) correction at the cluster-level.

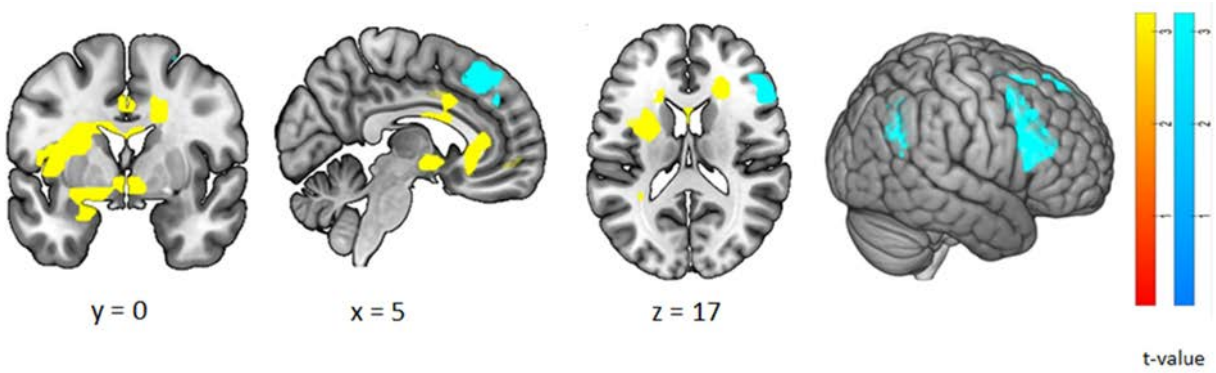

Figure 5. Whole-brain parametric analysis with changes in affect. Regions in which the BOLD signal was positively (yellow) or negatively (blue) related to changes in self-reported affect during image presentation in the emotion regulation task (across all conditions). Threshold: $p<.001$ (uncorrected) at the voxel- and $p<.05$ with family-wise error (FWE) correction at the cluster-level. For details cf. Table 2.

Neurobehavioral associations of up-regulation in fMRI and in daily life

Participants who had higher average affect in the laboratory also had higher affect in daily life ($r(63)=0.31$, $p=.01$, Figure S2).

Relation between VS activity and up-regulation in daily life. The association between VS activity during the up-regulation of positive emotions (PosUp>PosWatch) during fMRI was not related to the change in momentary affect during up-regulation in daily life ($r(63)=0.00$, $p=.97$).

Exploring whole-brain activity, changes in affect, and affect in daily life. Participants with lower average affect in daily life (mean-momentary affect during the ESM phase) had a stronger association between the engagement of emotion-related regions (across the whole brain) and changes in affect during the emotion regulation task ($r(61)=-0.30$, $p=.02$, Figure 6).

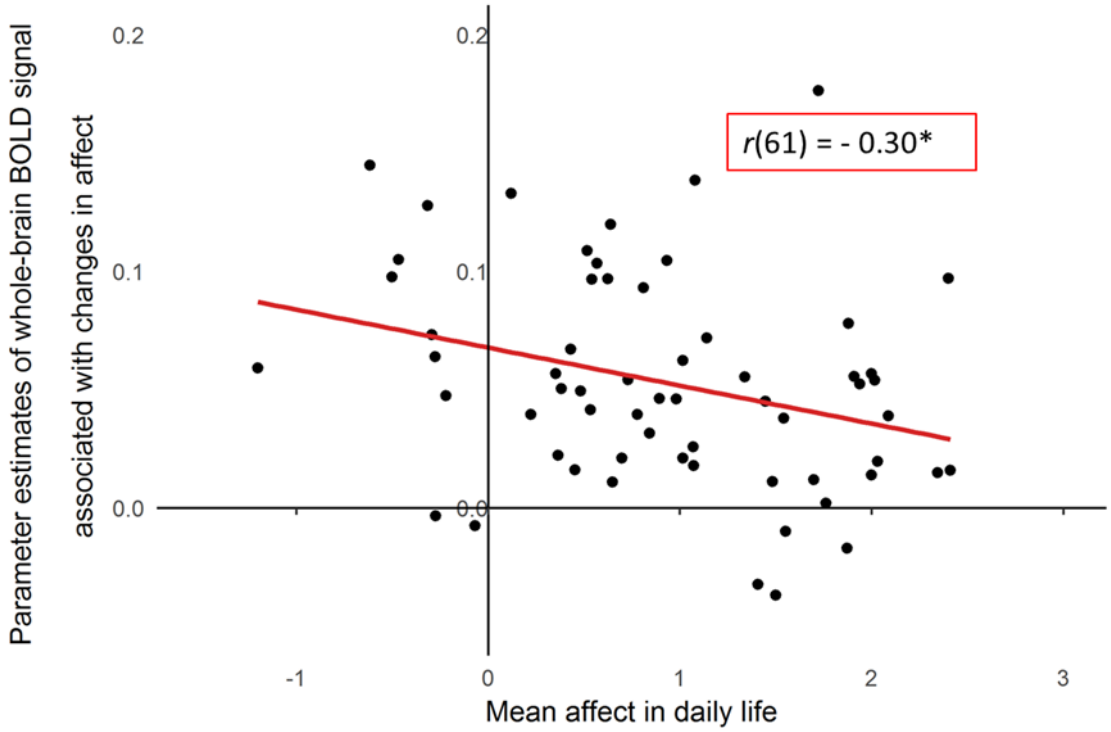

Figure 6. Link between affect in daily life and emotion-related brain activation in the laboratory. Mean momentary affect during the ESM phase was negatively correlated with the BOLD signal in medial frontal and subcortical emotion-related regions that showed a significant association with changes in affect (whole-brain parametric analysis; cf. Table 2 and yellow clusters in Figure 5). *p<.05

Discussion

This study investigated neurobehavioral associations of the up-regulation of positive emotions during fMRI and their relation to emotion regulation and affect in daily life. Specifically, we tested the involvement of the VS in the experience of affect during the up-regulation of positive emotions. We found that VS activation was increased during the up-regulation to images, relative to passively watching them, irrespective of their content's valence (positive or neutral). For positive images, increased VS activity was related to (1) higher between-person differences in self-reported affect and (2) greater within-person changes in affect during up-regulation. This shows that the VS is not only activated persistently across contexts but also tracks within-person changes in affect – suggesting a central role for the VS in the up-regulation of positive emotions. Against our hypothesis, VS activity

was not significantly related to changes in momentary affect when up-regulating positive emotions in daily life. However, an exploratory (whole-brain) parametric analysis showed that the lower a participant's general affect in daily life, the stronger the involvement of a set of medial frontal and subcortical emotion-related brain regions (including the VS) in changing the affect during the task in the laboratory.

VS activity during the up-regulation of positive emotions

We did not find the VS to be uniquely activated during the up-regulation to positive images but also during the up-regulation to neutral images. Behaviorally, however, the up-regulation to neutral images did not change participants' affect. Thus, in addition to the VS representing heightened positive experiences (Kringelbach & Berridge, 2009), it may serve another function during emotion regulation: VS activity may represent the general pursuit of an up-regulation goal (Ochsner et al., 2012). This idea is in line with the meta-analytic finding of increased VS activity during the up-regulation (as compared to the down-regulation) of *both* positive and negative emotions (Morawetz, Bode, Derntl, & Heekeren, 2017).

Like in a previous study (Greening et al., 2014), we found that increased activation in the VS was associated with higher average levels of self-reported affect when up-regulating positive emotions. Hence, the strength of VS recruitment can be considered a neural indicator of between-person differences in the ability to up-regulate positive emotions. We additionally found that increased activation in the VS was associated with greater moment-to-moment changes in affect during the up-regulation of positive emotions. Thus, the VS seems to be sensitive to varying regulatory efforts that may result from factors such as the specific type (Heiy & Cheavens, 2014) or intensity (Silvers, Weber, Wager, & Ochsner, 2015) of the emotion to be regulated.

Neural responses underlying changes in affect

Our data suggest other brain regions and networks (in addition to the VS) to reflect changes in affective experiences. The whole-brain parametric analysis showed that changes in affect – also an index of successfully up-regulating positive emotions – were associated with activation in several brain regions that have been implicated in affective functioning, such as amygdala, hippocampus,

ventromedial PFC, and striatum (cf. our Neurosynth decoding results). This finding aligns with the 'affective workspace hypothesis' that affective experiences rely on a flexible set of brain regions generally implicated in affective processing rather than on single brain regions representing positivity or negativity (Lindquist et al., 2016).

Next to activation in these emotion-related regions, changes in affect were also associated with *deactivation* of a fronto-parietal network, comprising lateral parietal and medial as well as lateral prefrontal cortices, which has previously been related to goal-directed cognition in general (Spreng, Stevens, Chamberlain, Gilmore, & Schacter, 2010) and the cognitive control of emotions in particular (Ochsner et al., 2012). Studied mainly in the context of the down-regulation of negative emotions, this network has been repeatedly shown active during cognitive reappraisal (Buhle et al., 2014) and associated with within-person changes in *negative* affective experiences (Silvers, Wager, Weber, & Ochsner, 2015). In our study, similar prefrontal control regions were relatively *less* recruited with positive changes in affect. Two possible explanations for this finding are:

First, deactivation in these prefrontal regions might indicate that increasing one's positive affect (e.g., during the up-regulation of positive emotions) is less cognitively challenging and involves less cognitive control ("less suppression") of subcortical emotion regions than, for example, the active down-regulation of negative emotions, as suggested previously (Morawetz et al., 2017). Put differently, the down-regulation of negative emotions may require (more) cognitive effort to change an emotional response (e.g., by altering its meaning through reappraisal; Buhle et al., 2014) while the up-regulation of positive emotions may simply mean "admitting more" of an already existing emotional experience. Along these lines, participants find it easier to regulate their positive than their negative emotions (Kim & Hamann, 2007) and they do so more successfully in their daily lives (Heiy & Cheavens, 2014).

Second, the present finding suggests that enhancing momentary affective experiences might initiate distinct processes compared to other forms of emotion regulation. A recent study found (beside activations in emotion-related regions) deactivation in right fronto-parietal regions for the endogenous generation of positive emotions (Engen, Kanske, & Singer, 2017). Thus, enhancing positive affective

experiences may more strongly draw upon emotion generation rather than alteration processes, compared to decreasing negative affect (Silvers, Wager, et al., 2015; see also Figure S3 and Supplement 1.4). In sum, the fronto-parietal control network seems to be relevant for the management of both positive and negative affective experiences.

Relating neurobehavioral associations with emotion regulation and affect in daily life

The hypothesized link between VS activity related to changes in affect during fMRI and shifts in momentary affect when up-regulating in daily life was not supported by the data. Also the association between average levels of affect during fMRI and daily life was relatively weak in our study. This may be due to methodological constraints that limit the comparability between measures from the laboratory and the real world. It could be, for example, that the capacity to change one's emotional response upon instruction (as tested in the laboratory; Webb, Miles, & Sheeran, 2012), differs from the capacity to spontaneously regulate one's emotions (as usually done in daily life).

Interestingly, in participants with lower average affect in daily life, more variance of changes in affect could be explained with activation in a network of emotion-related brain regions (including the VS). This could indicate that the lower one's affect, the more this "core set" is involved in pro-hedonically changing one's affective states. Speculatively, such changes could reflect reward-related processes: that is, people with lower average affect have lower expectations of positive events, which leads to higher reward-prediction errors and higher mood (Eldar et al., 2016; Rutledge et al., 2014). Fittingly, a meta-analysis found activation in a similar affective network during the experience of reward as opposed to loss (Liu, Hairston, Schrier, & Fan, 2011) and recent ESM findings by our group suggest that people with lower well-being benefit more (in terms of their momentary affect) from daily positive events (Grosse Rueschkamp et al., 2018).

Limitations and further directions

There are several limitations: First, as partly discussed above, there are inherent differences between emotion regulation in laboratory-based tasks and in daily life (e.g., standardized stimuli vs. idiosyncratic events or instructed vs. spontaneous emotion regulation). Future studies could aim at establishing a greater parallelism by, for example, having participants engage in spontaneous rather

than instructed emotion regulation during fMRI or by experimentally manipulating daily events (cf. Koval & Kuppens, 2012).

Second, when investigating affective processes, it is important to consider the time-scale at which affective change occurs (Hollenstein et al., 2013). During fMRI, changes in affect are measured over seconds, whereas in daily life affective responses are assessed over minutes and hours. Thus, these two measures possibly capture different regulation processes (e.g., mood versus affect regulation).

Conclusion

By enhancing our positive emotional experiences, we can substantially improve the way we feel. This study highlights the relevance of the VS during the up-regulation of positive emotions by showing that not only between-person differences but also dynamic within-person changes in affect are supported by VS activity. The present findings further suggest that the ability to enhance one's positive experiences might rely less on cognitive control processes, as indicated by the relative deactivation in a fronto-parietal network, and more on the capacity to endogenously generate emotions. Finally, people who tend to feel worse in daily life show a stronger link between neural activation in emotion-related regions (including the VS) and changes in their affective experiences. Together, these findings emphasize the role of the VS for positive affect and underline the importance of including both laboratory and daily life measures in the study of emotion.

Supplementary material

1. Methods

1.1 Questionnaires

Big-Five Inventory (Lang & Lüdtke, 2005)

Satisfaction with Life Scale; (Diener, Emmons, Larsen, & Griffin, 1985)

Positive and Negatvie Affect Scale (Watson, Clark, & Tellegen, 1988)

Cognitive Emotion Regulation Questionnaire (Garnefski et al., 2001)

WHO-5 questionnaire (World Health Organization, 1998)

Emotion Regulation Profile-Revised (Nelis, Quoidbach, Hansenne, & Mikolajczak, 2011)

Dispositional Positive Emotion Scales (Shiota, Keltner, & John, 2006)

Hypomanic Personality Scale (Eckblad & Chapman, 1986)

1.2 Emotion regulation instructions during fMRI original German wording

„Willkommen bei dieser Studie.

Sie werden verschiedene Bilder sehen, die unterschiedliche Emotionen hervorrufen können. Vor jedem Bild erhalten Sie eine Anleitung, was Sie tun sollen. Diese lautet entweder 'VERSTÄRKEN oder 'ANSEHEN'.

Wenn Sie die Anleitung 'VERSTÄRKEN' sehen, versuchen Sie bitte, willentlich Ihre Gefühle zu verstärken, die Sie haben wenn Sie die Bilder sehen und welche die dargestellte Szene in Ihnen auslöst. Versuchen Sie also, Ihre Gefühle so intensiv wie möglich zu erleben.

Wenn die Anleitung 'ANSEHEN' lautet,

möchten wir Sie bitten, Ihre Gedanken und Gefühle einfach kommen und gehen zu lassen, so wie das natürlicherweise passiert.

Vor und nach jedem Bild werden Sie gefragt, wie Sie sich gerade fühlen. Bitte bewerten Sie Ihre Gefühle auf einer Skala von +3 (gut) bis -3 (schlecht), indem Sie mit der linken und rechten Pfeiltaste das entsprechende Kästchen wählen und dann mit der unteren Pfeiltaste Ihre Antwort einloggen.

Bitte antworten Sie spontan ohne langes Nachdenken. Sie haben max. 10 Sekunden Zeit um eine Antwort zu geben.

Nach einer kurzen Pause werden Sie dann ein weiteres Mal nach Ihren Gefühlen gefragt. Wenn Sie noch Fragen haben, stellen Sie diese bitte jetzt dem Versuchsleiter.“

Free English translation

„Welcome to this study.

You will see different images that can evoke different emotions. Before each image you will receive an instruction about what you should do. This can be either “INCREASE” or “WATCH”.

If you see the instruction „INCREASE”, please try to voluntarily increase your feelings, which you experience while viewing the images and which the depicted scene evokes in you. That is, try to experience your feelings as intensely as possible.

If the instruction is „WATCH“, we kindly ask you to just let your feelings and thoughts come and go, as it naturally happens.

Before and after each image you will be asked how you currently feel. Please rate your feelings on a scale from +3 (good) to -3 (bad) by choosing the corresponding box with the left and right button and then confirming your answer with the middle button.

Please answer spontaneously without thinking too long. You have maximally 10 seconds to give an answer.

After a short break you will be asked once more about your feelings. If you have questions, please ask the experimenter now.“

Table S1.

Results from the linear mixed-effects model predicting change in affect and affect in the emotion regulation task

	Self-reported affect (post-image)		Change in affect (post – pre-image rating)	
Variable	Estimate	*SE*	Estimate	*SE*
Fixed Effects				
Intercept	0.81***	0.08	-0.30***	0.06
Valence	0.76***	0.07	0.79***	0.09
Instruction	-0.04	0.06	-0.09	0.06
Valence x Instruction	0.28***	0.08	0.29**	0.09
Random Effects				
Within-person	1.34		1.94	
Between-person				
Intercept	0.32		0.10	
Valence slope	0.19		0.30	
Instruction slope	0.07		0.05	
Valence x Instruction slope	0.12		0.14	

***=p<.001 **=p<.01

Table S2.

Results from the linear mixed-effects model predicting affect when up-regulating positive emotions in daily life

	Momentary affect	
Variable	Estimate	*SE*
Fixed Effects		
Intercept	0.92***	0.11
Affect at previous occasion	0.14***	0.02
Degree of emotion regulation	0.29***	0.03
Random Effects		
Within-person	2.37	
Between-person		
Intercept	0.69	
Affect at previous occasion slope	0.01	
Degree of emotion regulation slope	0.02	

***=p<.001 **=p<.01

Table S3.
Whole-brain analysis for the interaction, main effect of valence, and main effect of instruction.

Brain regions	Side	k	t	MNI coordinates		
				x	*y*	*z*
Interaction: deactivation						
Medial frontal gyrus	R	144	4.92	6	48	42
Neutral > Positive						
Fusiform gyrus	L	6489	18.67	-27	-54	-9
Inferior frontal gyrus, pars triangularis	L	595	8.13	-54	24	21
Inferior frontal gyrus, pars triangularis	R	431	8.02	54	27	27
Supplementary motor area	L	227	5.39	-12	18	66
Middle frontal gyrus	R	307	5.25	24	15	48
Watch > Up-regulate						
Inferior parietal lobe	R	399	5.8	45	-51	54
Middle frontal gyrus	R	247	5.52	27	15	54

Note. Clusters labeled according to the anatomical labeling (AAL) atlas (Tzourio-Mazoyer et al., 2002). Threshold: $p<.001$ (uncorrected) at the voxel- and $p< .05$ with family-wise error (FWE) correction at the cluster-level

1.3 Deactivation for interaction: Follow-up analyses

Extracted parameter estimates from the cluster [6, 48, 42] showed a significant valence by instruction interaction, $F(1, 62)=19.5$, $p<.001$. Pairwise comparisons showed a significant difference ($t(62)=-4.57$, $p<.001$) between NeuUp (mean b=0.21) and PosUp (mean b=0.04) as well as ($t(62)=4.05$, $p<.001$) between NeuUp and NeuWatch (mean b=0.04; Figure 3), suggesting that activation in this cluster was driven by increased activation in NeuUp.

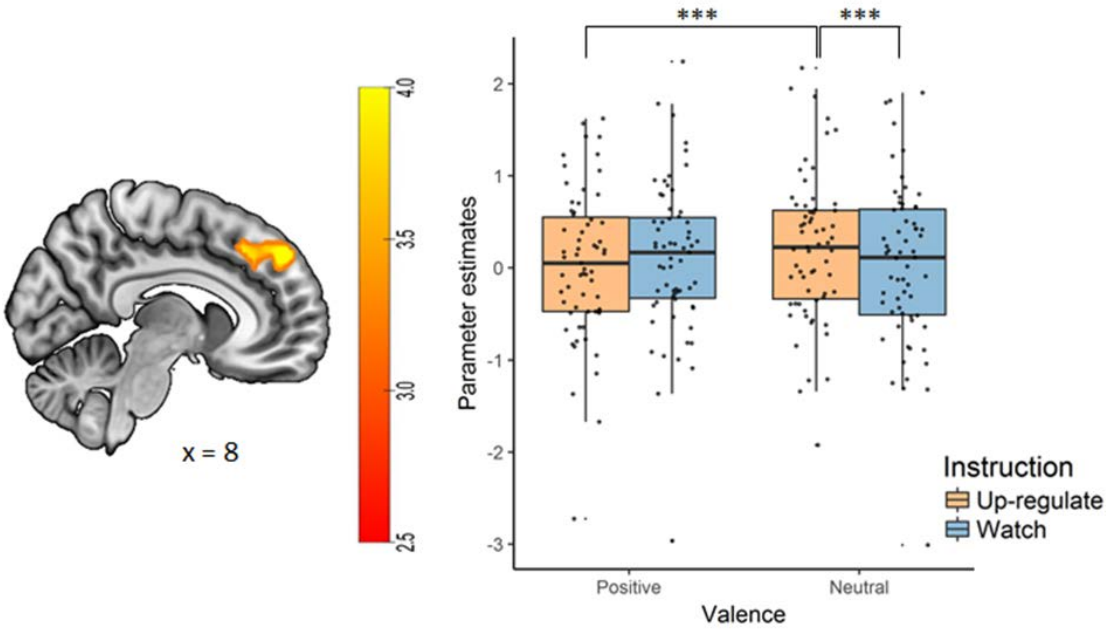

Figure S1. Brain activation in the emotion regulation task (inverse interaction). Decreased brain activation was found in the right dorsomedial prefrontal gyrus for the interaction of valence and instruction. Follow-up analyses indicate that there was significantly less activation for up-regulating to positive images and passively watching neutral images than for up-regulating to neutral images. (No significant voxels were found for the main interaction contrast, cf. Table 1.) Threshold: $p<.001$ (uncorrected) at the voxel- and $p<.05$ with family-wise error (FWE) correction at the cluster-level. ***=$p<.001$

Table S4.
Neurosynth terms that show an association with activation in brain regions that are parametrically modulated by changes in affect

Neurosynth term	*r*
Increased activation	
amygdala	0.190
fa	0.151
hippocampus	0.149
vmpfc	0.147
amygdala hippocampus	0.138
neutral	0.136
arousal	0.135
faces	0.135
ventromedial	0.134
ventromedial prefrontal	0.133
callosum	0.131
corpus callosum	0.131
corpus	0.130
cortex vmpfc	0.129
amygdala response	0.127

emotion	0.124
putamen	0.123
emotional	0.122
hippocampal	0.120
valence	0.120
cingulate cortex	0.117
fearful	0.117
pain	0.116
limbic	0.116
reactivity	0.115
Decreased activation	
frontal	0.258
working memory	0.218
working	0.216
inferior frontal	0.211
task	0.206
parietal	0.202
inferior	0.196
comprehension	0.189
sentences	0.181
sentence	0.171
demands	0.169
linguistic	0.166
tasks	0.164
dorsolateral	0.161
language	0.160
parietal cortex	0.157
frontoparietal	0.156
fronto parietal	0.155
prefrontal	0.154
frontal gyrus	0.154
theory mind	0.148
syntactic	0.143
mind tom	0.142
speaker	0.138
semantic	0.130

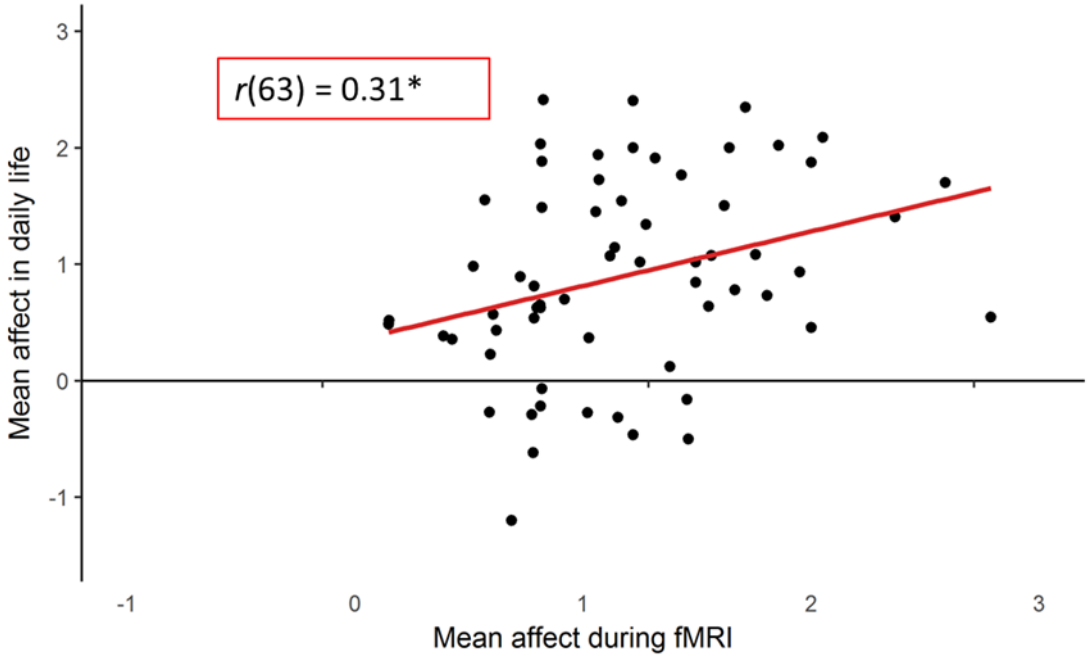

Figure S2. Association between mean affect during fMRI and mean affect in daily life. Mean self-reported affect during fMRI was positively correlated with mean momentary affect in daily life. *=*p* <.05.3

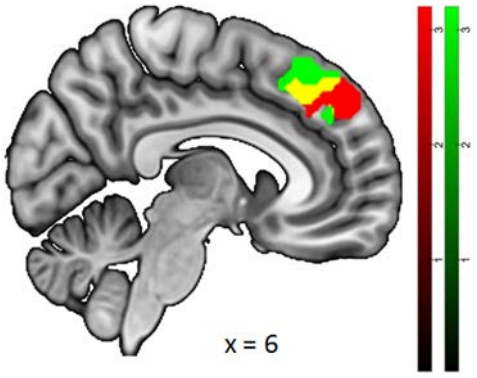

Figure S3. Overlap between brain activation in the emotion regulation task (inverse interaction) and in the whole-brain parametric analysis with changes in affect. The BOLD signal that was negatively correlated with changes in affect (green; whole-brain parametric analysis across all conditions, see also Table 2 and Figure 5) partially overlaps (yellow) with deactivation for the interaction of valence and instruction (red; whole-brain analysis, [6, 48, 42], T=4.92, see also Table S2). Threshold: p<.001 (uncorrected) at the voxel- and p<.05 with family-wise error (FWE) correction at the cluster-level. ***=p<.001

1.4 Deactivation for interaction and deactivation of whole-brain parametric analysis

In its medial part, the fronto-parietal network overlapped with the *deactivation* of the dorsomedial prefrontal cortex (dmPFC) cluster found in the interaction of valence and instruction (see above and Figure S3 for the overlap). As this cluster was solely deactivated during the up-regulation of positive emotions, it further supports the idea that successful up-regulation of positive emotions, at least partly, depends on the deactivation of prefrontal control systems. However, if one understands the deactivation of the dmPFC cluster as a significant *increase* in activation for the up-regulation to neutral images, this cluster could indicate that, similar to the regulation of negative emotions, regulatory efforts to neutral images require auxiliary cognitive functions (Miller & Cohen, 2001). However, these seem to be dissociated from changes in affect, as indicated by the behavioral data and the whole-brain parametric analysis

9 Paper III

Higher Well-Being is Related to Reduced Affective Reactivity to Positive Events in Daily Life

Johanna M. Grosse Rueschkamp
Humboldt-Universität zu Berlin, Germany
Peter Kuppens
KU Leuven, Belgium
Michaela Riediger
Friedrich-Schiller-Universität Jena, Germany
Elisabeth S. Blanke
Humboldt-Universität zu Berlin, Germany
Annette Brose
Humboldt-Universität zu Berlin, Berlin, Germany
KU Leuven, Belgium

This article was published as:

Grosse Rueschkamp, J. M., Kuppens, P., Riediger, M., Blanke, E. S., & Brose, A. (2018). Higher well-being is related to reduced affective reactivity to positive events in daily life. *Emotion.* http://dx.doi.org/10.1037/emo0000557.

This is the final author copy before copy editing.

Author Note

The research leading to the results reported in this paper was supported in part by a grant awarded to Annette Brose by the German Research Foundation [Deutsche Forschungsgemeinschaft, DFG], BR 3782/3-1, as well as by the Research Fund of KU Leuven (GOA/15/003), and by the Interuniversity Attraction Poles programme financed by the Belgian government (IAP/P7/06); Data collection for the Multi-Method Ambulatory assessment was supported by the German Federal Ministry for Education and Research Grants MPI001and 01UW0706 and the Max Planck Society for the Advancement of Science. Data collection of the COGITO study was supported by a grant from the Innovation Fund of the President of the Max Planck Society (M.FE.A.BILD0005) to Ulman Lindenberger. Data collection for Study 5 was supported by a grant from the Humboldt Graduate School "Self-Regulation Dynamics Across Adulthood and Old Age: Potentials and Limits", Humboldt-Universität zu Berlin, to Johanna M. Grosse Rueschkamp. We thank Julia Delius for editorial assistance. Johanna M. Grosse Rueschkamp is a pre-doctoral fellow of the International Max Planck Research School on the Life Course (LIFE, www.imprs-life.mpg.de; participating institutions: Max Planck Institute for Human Development, Freie Universität Berlin, Humboldt-Universität zu Berlin, University of Michigan, University of Virginia, University of Zurich).

Correspondence concerning this article should be addressed to Johanna M. Grosse Rueschkamp, Humboldt-Universität zu Berlin, Institut für Psychologie, Emmy Noether Independent Junior Research Group “Adaptation to Major Life Events,” Unter den Linden 6, 10099 Berlin, Germany. Email: johanna.grosserueschkamp@hu-berlin.de

Supplemental material is available for review:
https://osf.io/cp87m/?view_only=a03a97b708bc48b18c9c5f3e20e15168

Abstract

Within the study of emotions, researchers have increasingly stressed the importance of studying individual differences in emotion dynamics and emotional responding and the way these relate to more stable differences in well-being. However, there is no clear picture regarding affective reactivity to positive events and how different emotional reactions relate to differences in well-being, particularly higher levels of well-being. Theoretical work and empirical findings from different lines of research (e.g. clinical studies, aging literature, positive and personality psychology) support either of two predictions: Higher well-being is related to an enhanced or reduced affective reactivity to positive events in daily life. Testing these opposing predictions, we examined global well-being and affective reactivity to daily positive events in six studies using the experience-sampling or daily diary method (*N*s = 70, 66, 95, 200, 76, and 101). Global well-being was measured with various indicators and a well-being composite score. Across the majority of studies, we found that higher global well-being was associated with reduced affective reactivity to positive events in daily life, as shown by smaller decreases in momentary negative affect. In three of the six studies, higher well-being composite scores were also associated with smaller increases in momentary positive affect. These findings seem to suggest that people with higher global well-being profit less from the joy of a positive event they experience in daily life. Instead, for people with lower well-being, positive events might be a meaningful way to brighten one's momentary mood.

Keywords: well-being, positive events, affective reactivity, emotion dynamics, experience-sampling method

Levels of well-being differ across individuals. These differences in well-being are not only apparent in the presence or absence of psychological maladjustment, but also in different levels of positive indicators of psychological adjustment, such as positive affectivity, happiness, or life satisfaction (Houben, Van Den Noortgate, & Kuppens, 2015). Research has uncovered various psychological factors that are associated with well-being, including, for example, personality traits (Deneve & Copper, 1998). In recent years, however, researchers have increasingly stressed the importance of investigating emotion dynamics and looking at individual differences in patterns of emotional responding over time when studying well-being. One form of emotion dynamics is affective reactivity, which can be conceptualized as the change in momentary affect in response to an external event (Sliwinski, Almeida, Smyth, & Stawski, 2009). Regarding negative events, research has revealed stronger negative reactions in people with lower levels of well-being and poorer health (e.g. Charles, Piazza, Mogle, Sliwinski, & Almeida, 2013; Piazza, Charles, Sliwinski, Mogle, & Almeida, 2013). The picture is less clear, however, for reactivity to positive events. Some studies have found a link between increased affective reactions and higher well-being (Carl et al., 2014). Conversely, other studies have reported decreased affective reactions to daily positive events in people with higher levels of well-being (Oishi et al., 2007). Relatedly, theoretical explanations exist for both directions of effects. Given the discrepancy in theoretical reasoning and empirical findings, the purpose of this study was to integrate the theoretical arguments and findings from the diverse lines of research (e.g., clinical, positive psychology, and aging literature) and to provide a large-scale and systematic test of whether higher global well-being is associated with enhanced affective reactivity to positive events in daily life or whether individuals with higher global well-being show decreased reactivity.

To do this, we analyzed data from six different studies that used experience-sampling and daily diary methods. In accordance with Diener and colleagues' (1999) definition of well-being, which includes both high levels of positive and low levels of negative affect, as well as life satisfaction (Diener, Suh, Lucas, & Smith, 1999), we assessed global well-being with indicators that measure cognitive and affective as well as positive and negative aspects of well-being. These indicators represent self-reported stable individual differences in how people feel and think about their lives in

general. We investigated affective reactivity to positive events including reactions to both momentary positive and negative affect. The use of these two outcome variables is in accordance with the finding that positive events are associated with positive and negative affect at the within-person level (Zautra et al., 2005). This approach is also in line with our study aim to integrate different literatures and findings from previous studies that have analyzed both ends of the valence dimension of affect as outcome variables.

Increased Reactivity to Positive Events for Individuals With Higher Global Well-Being?

There is reason to believe that the experience of intense positive emotions in everyday situations has adaptive benefits, and that intense affective reactions to daily positive events are therefore related to higher levels of global well-being. Research in the realm of positive psychology suggests that intense momentary experiences of positive emotions are linked to various beneficial outcomes such as increased global physical and subjective well-being (Lyubomirsky et al., 2005). Specifically, positive emotions are thought to broaden people's attention and thinking in ways that enable them to build up a host of personal resources (cognitive, psychological, social and physical). The latter eventually influence their global well-being (Fredrickson, 2001). Accordingly, it has been shown that broadened coping, thinking, and positive affect reciprocally enhance each other over a period of five weeks (Fredrickson & Joiner, 2002).

Another theoretical account, the savoring account, adds to this more general notion on the adaptive function of enhanced positive emotions. Savoring, defined as the capacity to attend to the joys, pleasures, and other positive feelings that we experience in our lives (Bryant, 2003; Bryant & Veroff, 2007), results in the maximization and prolonging of positive experiences, that is, the enhancement of momentary affect. This, in turn, is thought to be positively related to people's well-being more generally. Indeed, multiple studies have successfully linked the habitual use of savoring with higher levels of global well-being (Bryant, 2003; Quoidbach, Berry, Hansenne, & Mikolajczak, 2010; Smith & Hollinger-Smith, 2015). Likewise, savoring tendencies in daily life, as measured through experience-sampling and daily diary studies, have been linked to momentary and daily measures of experienced mood and positive affect (S. L. Gable, Reis, Impett, & Asher, 2004; Gentzler,

Morey, Palmer, & Yi, 2013; Langston, 1994). Although savoring is mostly considered to reflect emotion regulation rather than unmodulated affective reactions, findings on the positive effects of savoring in daily life could be taken as indirect evidence for a positive link between affective reactivity and higher well-being. More specifically, savoring positive experiences enhances and prolongs momentary positive mood in daily life. This should also be reflected in enhanced affective reactions to positive events. In extension, enhanced affective reactivity to positive events, like savoring, should be related to higher levels of well-being. In line with this reasoning, one daily diary study that investigated affective reactions to positive events indeed found increased reactivity to positive events in participants with higher global positive affectivity and lower depressive symptoms (Carl et al., 2014).

Further support for a potentially positive link between global well-being and reactivity to positive events comes from research in personality psychology. Extraversion, in particular, has been linked to differences in levels of affect and affective reactions. It has been proposed, for example, that the positive correlation between extraversion and higher dispositional positive affect is due to enhanced affective reactivity to positive stimuli and events (Larsen & Ketelaar, 1991). Several laboratory studies have indeed shown increased reactivity in the context of positive mood inductions in people with higher levels of extraversion (Gross, Sutton, & Ketelaar, 1998; Larsen & Ketelaar, 1991). This link was not replicated in more naturalistic settings, however, despite the generally higher positive emotionality of extraverts (Howell & Rodzon, 2011; Lucas et al., 2008).

Finally, some clinical research seems to suggest a positive link between affective reactivity to positive events and higher global well-being—because it reveals decreased reactions to positive events in individuals with low levels of well-being. More specifically, one prominent view from depression research holds that major depressive disorder attenuates affective reactions to specifically positive stimuli (Bylsma et al., 2008). This phenomenon, known as positive attenuation, conforms to mood-facilitation theory, which states that moods facilitate the experience of like-valenced emotions (Rosenberg, 1998). A meta-analysis provided empirical support for this phenomenon: Affective reactions to positive stimuli in the laboratory were decreased in depressed participants, compared to

healthy controls (Bylsma et al., 2008). Since depression is characterized by low overall well-being, among other things, these findings support the emerging picture of lower well-being and reduced affective reactivity. From the opposite perspective, one would expect increased reactivity to positive events in individuals with higher levels of well-being.

Decreased Reactivity to Positive Events for Individuals With Higher Global Well-Being?

Despite this support for the assumption of enhanced affective reactivity in people with higher levels of global well-being, there are theoretical considerations and empirical evidence from other fields of study that lead to opposing predictions. One such account proposes that people with higher global well-being profit less from the joy of a positive event they experience in daily life (Oishi et al., 2007). The reason for this is that people with higher levels of global well-being pay less attention to single positive events as they experience them frequently, leading to a habituation process. This idea was tested in a daily diary study in which participants reported positive events as well as their daily satisfaction. Global well-being was measured through the Satisfaction with Life Scale (SWL; Diener, Emmons, Larsen, & Griffin, 1985). Those participants with higher life satisfaction were indeed the ones with the weakest within-person relationship between daily positive events and daily satisfaction.

Empirical studies from other lines of research further support this finding. A study on emotional development across the adult life span investigated affective reactivity to daily positive events in younger and older adults. The older participants, relative to the younger ones, showed smaller increases in positive affect, and, extending previous findings, also smaller decreases in negative affect in reaction to positive events (Röcke et al., 2009). Even though the authors did not test whether global well-being moderates affective reactivity, older people had higher levels of well-being in this study, as indicated by significantly higher average levels of trait positive affect. Serving as indirect evidence, this may also point to lower affective reactivity to positive events for people with higher levels of global well-being. Röcke and colleagues (2009) furthermore speculated that reduced affective reactivity to daily positive events is one way for older people to keep their overall affective states more stable, which, in turn, would contribute to their generally higher levels of well-being (e.g.

Carstensen, Pasupathi, Mayr, & Nesselroade, 2000; Riediger, Schmiedek, Wagner, & Lindenberger, 2009).

The idea that reduced affective reactivity is associated with higher well-being is in line with recent research on emotion dynamics. In fact, there is strong evidence from a recent meta-analysis that higher global well-being is associated with a less variable and more stable emotional life, characterized by less variable, less unstable, and less inert emotions (Houben et al., 2015). While the associations were stronger for negative emotions, positive emotional stability has also been associated with well-being (Gruber et al., 2013; Houben et al., 2015). Events and event-related variability in affect were not taken into account in these studies. Yet, it is reasonable to assume that the more adaptive patterns of affect dynamics should be reflected in less strong affective reactions rather than intense affective reactions to daily events. Hence, people with higher well-being should have relatively stable emotion dynamics, including reduced affective reactivity to positive events as compared to people with lower well-being.

This assumption is complemented by the literature on affect intensity, which suggests that intense positive emotions are accompanied by emotional costs. For example, the opponent-process theory posits that in order to produce intense positive reactions in to a positive event, one first needs to experience intense negative affect (Solomon, 1980). Similarly, events are proposed to be appraised relatively to other events (Parducci, 1968; Smith, Diener, & Wedell, 1989). Therefore, for an event to be appraised as particularly positive, one must have experienced events that were appraised as particularly negative. The underlying rationale of these theories is that affective judgments are made relative to previous affective experiences. In line with this view, affect intensity, the strength with which individuals typically experience emotions, generalizes over emotion categories (Larsen & Diener, 1987). With regard to between-person differences in well-being, this seems to imply that enhanced affective reactions to positive events cannot be related to highest levels of well-being—because the amplification of positive feelings is partly due to the experience of negative feelings.

Propositions of the opponent-process theory can also be linked to the clinical literature. Major depressive disorder and elevated levels of depressive symptoms are associated with enhanced affective

reactivity to positive events. In particular, studies have revealed stronger decreases in negative affect and stronger increases in positive affect in reaction to daily positive events in people with enhanced levels of depression (Bylsma et al., 2011; Nezlek & Plesko, 2003; Peeters, Nicolson, Berkhof, Delespaul, & deVries, 2003; Thompson et al., 2012). This effect is referred to as "mood-brightening effect", and it supports the idea of opponent-process models. More importantly, these findings seem to suggest reduced affective reactions to positive events in people with higher levels of global well-being, because they provide evidence for the opposite: increased reactions to positive events in depressed people that characteristically have low levels of well-being. Notably, these studies on affective reactions in depressed people in daily life rebut earlier findings from the laboratory that favored a mood attenuation effect in depression (see above)[1]. Together, the theoretical notions and empirical findings summarized in this section would predict that people with higher levels of global well-being should be those with smaller increases in positive affect and smaller decreases in negative affect when experiencing positive events.

The Present Study

Taken together, two different pictures emerged on how affective reactivity to positive events might be related to global well-being. Theoretical arguments exist for either of the two pictures—increased or decreased reactivity to positive events (i.e., the mood-facilitation versus opponent-process theory). Empirically, the picture of increased reactivity in people with higher levels of global well-being is largely based on laboratory studies or studies using trait and other retrospective measures of affective reactivity and well-being (Bryant, 2003; Carl et al., 2014). Instead, the picture of decreased reactivity in people with higher levels of global well-being is to a greater extent based on studies that employed methodological approaches particularly useful for investigating affective reactivity in real life, such as the experience-sampling method (Bylsma et al., 2011; Oishi et al., 2007). Finally, studies in support of either picture differ in their use of global well-being indicators (e.g., depressive symptoms versus life satisfaction) and their measures of momentary affect (i.e., momentary positive versus momentary negative affect). This diversity calls for a large-scale and systematic test of the issue at stake, and this is what we aimed to do in this study.

We tested whether higher levels of global well-being are associated with increased or decreased reactivity to positive events in daily life. We tentatively expected higher global well-being to be related to reduced affective reactivity to positive events, as indicated by most studies that used similar methodological approaches. These studies, using experience sampling and other intense longitudinal designs, generate information on affective reactivity by using online reports of feelings in ecologically valid environments. Global well-being is assessed through retrospective reports in these studies. The former captures emotional experiences in the moment, while the latter is supposed to rely on memory and more general beliefs about oneself (i.e., representing semantic knowledge; (Robinson & Clore, 2002a, 2002b). Thus, these measures capture distinguishable aspects of the person and share comparatively little method variance. While experience sampling studies lack experimental control (e.g., of exposure to certain events and the report of such), they are informative on the link between well-being and momentary affective processes as they occur in real life.

To test the relationship between affective reactivity and well-being, we used data from six studies that measured positive events and momentary affect in daily life, using the experience-sampling or daily diary method. We expected the effect of major interest, the moderating effect of global well-being on affective reactivity, to be observable for both positive and negative affect as outcome variables.

Method

The data used in this study mostly come from previously published studies (central references are named below), so sample sizes were not specifically determined for this study specifically. They were based on previous experience-sampling/ daily diary studies conducted by the respective principal investigator.

Study 1. This study was conducted with a sample of 70 students (50,0 % women), aged between 20 and 30 years (M = 25.6, SD = 2.7 years) from Berlin, Germany (see also Blanke & Brose, 2017). The experience-sampling phase was scheduled between two laboratory sessions that were used for initial instructions and questionnaires. For the entire experience-sampling phase, which was conducted throughout nine consecutive days, participants carried smartphones (Huawei Ascend G330)

with them. On each day, six beeps were scheduled semi-randomly within a time frame of 12 hours. Participants responded to 54 beeps on average (*SD* = 3.2). They were, on average, reimbursed with a total of 65 Euros (depending on the number of beeps completed). The study was approved by the ethics committee of the Humboldt-Universität zu Berlin.

Study 2. The analyses were conducted with a sample of 66 participants (48.5% women), aged between 18 and 30 years (*M* = 24.9, *SD* = 3.8) from three different sites in Germany. The participants were part of a larger sample (*N* = 378) ranging from 14 to 86 years of age from the first assessment wave of the Multi-Method Ambulatory Assessment Project (see also Riediger, 2018; Riediger et al., 2009). Only a subsample of this larger sample was used in the present study in order to have a comparable age range of participants across studies. After an initial pre-interview during which participants filled in questionnaires, the experience-sampling phase started with six daily assessments (scheduled semi-randomly within a 12-hour time frame) on nine days throughout three weeks, during which participants carried smartphones (Nokia E50). Participants responded to 55 beeps on average (*SD* = 4.2). They were reimbursed with a total of 100 Euros. The study was approved by the ethics committee of the Max Planck Institute for Human Development, Berlin.

Study 3. This sample consisted of 95 students (56.1% women) aged between 18 and 24 years (*M* = 19.1, *SD* = 1.3) from Leuven, Belgium. The sample was drawn from a larger participant pool (*N* = 439) that included participants who had been pre-screened for depressive symptoms in order to ensure a wide range of well-being levels (see also Brans, Koval, Verduyn, Lim, & Kuppens, 2013). Participants came to the laboratory for an introductory session, during which they received initial instructions, filled in questionnaires, and received a palmtop computer (Tungsten E2). During the subsequent 7-day experience-sampling phase, participants could respond to a maximum of 10 beeps that were scheduled semi-randomly (within a 12-hour time frame) throughout each day. Participants responded to 61 beeps on average *(SD* = 4.4). They were reimbursed a total of 70 Euros. The study was approved by the ethics committee of the University of Leuven.

Study 4. This study was conducted with a sample of 200 students (55.0 % women), aged between 17 and 24 years (*M* = 18.3, *SD* = 1.0) from Leuven, Belgium. As in Study 3, participants were

drawn from larger participant pool (N = 686) that included participants who were pre-screened for depressive symptoms. After an introductory session, during which participants filled in questionnaires, participants received a smartphone (Motorola Defy Plus) that they carried with them for the next seven days, programmed to beep 10 times semi-randomly throughout the day (within a time frame of 12 hours). Participants responded to 61 beeps on average (SD = 6.3). Participants were reimbursed with a total of up to 120 Euros. The study was approved by the ethics committee of the University of Leuven.

Study 5. This study was conducted with a sample of 76 students (50.7% women), aged between 20 and 25 years (M =21.9, SD = 1.6) from Berlin, Germany. The experience-sampling phase was part of a larger study that also included a functional magnetic resonance imaging (fMRI) session (the order of fMRI session and experience-sampling phase was counterbalanced between participants). During an introductory session, participants filled out questionnaires and received instructions for the experience-sampling phase starting the following day. Participants carried smartphones (Huawei Ascend G330) with them, which were programmed to beep semi-randomly 6 times (within a 12-hour time window) for 2 periods of 5 days, separated by a break of 2 days. Participants responded to 56 beeps on average (SD = 8.4). Participants were reimbursed with a total of up to 90 Euros. The study was approved by the ethics committee of the Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig.

Study 6. The sample consisted of 101 participants (51.5% women) aged between 20 and 31 years (M = 25.6, SD = 2.7) from Berlin, Germany. All participants took part in a larger study, the COGITO study. Participation in this study included a microlongitudinal testing phase of an average of 101 occasions (SD = 2.7) with 1-hour close-to-daily testing sessions at the laboratory (the 101 occasions were spread out across 162 days, on average). Each participant also took part in an additional pre- and posttest of 2 weeks (see also Brose, Schmiedek, Lövdén, & Lindenberger, 2011). Again, only a subsample of the COGITO study was used in order to have a comparable age range across all studies. During the daily testing sessions, participants completed, among other tasks, daily diary self-reports. Participants were reimbursed with a total of 1450 to 1950 Euros, depending on how

quickly they completed the study. The study was approved by the ethics committee of the Max Planck Institute for Human Development, Berlin.

Measures

This is a summary of the main variables assessed in all studies. For an overview of the measurement specifics for each study, see Table 1.

Momentary positive and negative affect: Affective experiences were measured at each occasion using various affect items. These were then used to calculate aggregate scores for positive affect (PA) and negative affect (NA) at each occasion (i.e., each beep / day). Importantly, Study 5 used bipolar affect items for the measurement of momentary affect. These items thus represent an overall score of momentary affect, which is reported under PA in the following.

Positive events: Positive events were assessed by one of three means: (a) event occurrence (Studies 1, 2, and 3), i.e., by asking participants to report whether anything pleasant had happened since the last beep; (b) event intensity (Studies 4 and 5), i.e., by asking participants to rate the intensity of the most pleasant experience they had had since the last beep; or (c) a list of event categories (Study 6), i.e., by asking participants to report if they had experienced different types of events, followed by an evaluation of the valence of the events on that day. The reported positive events from the list of event categories were then dummy-coded, while event intensity was used as a continuous variable.

Global well-being: Global well-being was assessed with the following trait questionnaires: the Satisfaction with Life Scale (SWL; Diener et al., 1985); the Life Appraisal Scale (SLB; Ferring, Filipp, & Schmidt, 1996), also measuring life satisfaction; the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988), measuring affective well-being; the CES-D (Radloff, 1977), measuring depressive symptoms. Individual scores for each questionnaire were calculated by averaging across each scale's scores. Additionally, aggregated PA and aggregated NA scores from the experience sampling (aggregated per person and across time) were taken as an additional indicator for global well-being. They thus represent average levels of PA and NA across each study period.

Table 1.
Overview of Measure Specifics for Each Study

Study 1 (*N* = 70, Germany)	**Study 2** (*N* = 66, Germany)	**Study 3** (*N* = 95, Belgium)	**Study 4** (*N* = 200, Belgium)	**Study 5** (*N* = 76, Germany)	**Study 6** (*N* = 101, Germany)
Measurement method (state level)					
ESM	ESM	ESM	ESM	ESM	Daily Diary
PA items (ESM / Daily Diary)					
• Relaxed • Joyful • Content	• Joyful • Content	• Relaxed • Happy	• Relaxed • Happy	• Relaxed / Tense • Bad / Good • Well / Unwell • Tired / Awake • Agitated / Calm • Full of Energy / Without Energy	• Enthusiastic • Excited • Strong • Interested • Proud • Inspired • Determined • Attentive • Active
NA items (ESM / Daily Diary)					
• Downhearted • Nervous • Distressed	• Downhearted • Disappointed • Angry • Nervous	• Sad • Depressed • Anxious • Angry	• Sad • Depressed • Anxious • Angry		• Distressed • Upset • Nervous • Jittery
Answering scale					
7-point scale from 0 (*does not apply at all*) to 6 (*applies strongly*)	7-point scale from 0 (*does not apply at all*) to 6 (*applies strongly*)	Slider scale from 0 (*not at all*) to 100 (*very much*)	Slider scale from 0 (*not at all*) to 100 (*very much*)	7-point scale from -3 (*not at all*) to +3 (*very strongly*)	8-point scale from (*does not apply at all*) to 7 (*applies very well*)
Reference frame					
Since waking up/ since the last beep	Current (at the moment of the beep)	Current (at the moment of the beep)	Current (at the moment of the beep)	Current (at the moment of the beep)	Current (at the moment of the self-report)
Event occurrence (question)					
Did anything pleasant happen since the last beep?	Since the last time we asked / waking up, have you done anything pleasurable or that made you happy, or thought about anything like this?	Think about the most positive event that has occurred since the last beep. How intense was this event?	Think about the most positive event that has occurred since the last beep. How intense was this event?	Think about the most pleasant event that has occurred since the last beep / waking up. How much did you have positive feelings from the event?	Since the last time you came to the lab or later during this day, did you or do you expect to experience the following event? Event types: argument, disagreement,

					overload, some event related to work, a friend, health, leisure, to finances
Answering scale					
Yes / No	Yes / No	Yes / No	Slider scale from 0 (*there was no event*) to 100 (*very positive*)	7-point scale from 0 (*not at all*) to 6 (*very much*)	4-point scale from: 0 *(did not occur)* to 4 *(did occur and affected me strongly)*; Valence rating*: negative*, *slightly negative*, *neutral*, *slightly positive*, *positive;* aggregated into dichotomous variable (0/1)
Global well-being (trait level)					
Life satisfaction					
SWL, 5 items	LSB, 15 items	SWL, 5 items	SWL, 5 items	SWL, 5 items	SWL, 5 items
Answering scale					
7-point scale from 1 (*completely disagree*) to 7 (*completely agree*)	7-point scale from 1 (*does not apply to me at all*) to 7 (*completely applies to me*)	7-point scale from 1 (*completely disagree*) to 7 (*completely agree*)	7-point scale from 1 (*completely disagree*) to 7 (*completely agree*)	7-point scale from 1 (*completely disagree*) to 7 (*completely agree*)	8-point scale from 0 (*not at all*) to 7 (*very often*)
Affectivity					
PANAS, 20 items + 6 additional adjectives		PANAS, 20 items	PANAS, 20 items	PANAS, 20 items	PANAS, 20 items
Answering scale					
5-point scale from 1 (*very little to never*) to 5 (*extremely*)		5-point scale from 1 (*very little to never*) to 5 (*extremely*)	5-point scale from 1 (*very little to never*) to 5 (*extremely*)	5-point scale from 1 (*very little to never*) to 5 (*extremely*)	8-point scale from 0 (*does not apply at all*) to 7 (*applies very well*)
Depressive symptoms					
CES-D, 20 items		CES-D, 20 items	CES-D, 20 items		CES-D, 20 items
Answering scale					
5-point scale from 0 (never) to 4 (always)		4-point scale from 1 *(rarely or none of the time, less than 1 day)* to 4 *(most or all of the time, 5–7 days)*	4-point scale from 1 *(rarely or none of the time, less than 1 day)* to 4 *(most or all of the time, 5–7 days)*		8-point scale from 0 (*does not apply at all*) to 7 (*applies very well*)

Note. ESM = experience sampling method; PA = positive affect; NA = negative affect; SWL = Satisfaction with Life Scale; LSB = Life Appraisal Scale; PANAS = Positive and Negative Affect Scale; CES-D = Center for Epidemiologic Studies Depression Scale

Well-being composite scores: We used principal component analyses to additionally compute well-being composite scores for each study[2]. These analyses revealed that in each study well-being had one underlying factor that accounted for at least 50% of the variance[3], thus conforming to previous studies that used composite scores of well-being (Sheldon & Elliot, 1999). Moreover, the loadings of the different indicators were rather high and comparable in size, which means that they contributed to equal amounts of the variances in the component scores. This supports our broad conceptualization of well-being, including positive and negative indicators as well as cognitive and affective components of well-being. The composite scores were used as additional indicators of well-being, with the advantage that they provide a simplified picture of the study's central findings.

Analyses

We used multilevel modeling to account for the hierarchical data structure, i.e., the nesting of occasions within participants. For our main analyses we used the following models (with PA and NA as criterion variables; equations are only provided for the example of PA):

$$PA_{ti} = \beta_{0i} + \beta_{1i} \times (\text{time}_{ti}) + \beta_{2i} \times (\text{positive event}_{ti}) + r_{ti} \qquad \text{(Level 1)}$$

$$\beta_{0i} = \gamma_{00} + \gamma_{01} \times (\text{well-being}_{i}) + \mu_{0i} \qquad \text{(Level 2)}$$

$$\beta_{1i} = \gamma_{10} + \mu_{1i}$$

$$\beta_{2i} = \gamma_{20} + \gamma_{21} \times (\text{well-being}_{i}) + \mu_{2i}$$

At Level 1, we modeled affective reactivity. In the equation, Level-1 PA of person *i* on occasion *t* is predicted by the intercept β_{0i}, the time-related change in affect β_{1i}, and the occurrence of a positive event, β_{2i}. At Level 2, we entered global well-being as a covariate. Here, β_{0i} is a function of the average initial level of PA (γ_{00}), as well as of between-person differences in global well-being (γ_{01}). The slope, β_{2i}, is a function of the average within-person relationship between the occurrence of a positive event and PA (γ_{20}), and, most importantly, person differences in well-being (γ_{21}). That is, γ_{21} reflects the moderating effect of global well-being on affective reactivity to positive events. For the time-related change in affect, β1i, we modeled an average linear slope at Level 2. All residual variances (at Level 1 and Level 2; r_{ti}, μ_{0i}, μ_{1i}, μ_{2i}) were modeled. For all Level 2 predictors (i.e., global well-being indicators), separate multilevel models were estimated. Event occurrence, the Level-1

predictor, was person-mean centered, while all well-being indicators, the Level-2 predictors, were grand-mean centered. Affective reactivity in Studies 1 to 3 and 6 can be interpreted as the deviation in momentary affect on occasions at which participants reported a positive event, in comparison to levels of momentary affect on occasions without a positive event. In contrast, in Studies 4 and 5, affective reactivity is the change in levels of momentary affect as a function of the change in perceived intensity of the event.

To get at metrics that are comparable across studies, other than the unstandardized regression coefficients that are commonly obtained from multilevel models, we calculated Pseudo-R^2 statistics, as an approximation for the strength of the interaction. This Pseudo-R^2 statistic was calculated as the change in slope variance from a baseline model (including the Level-1 and Level-2 predictors without the cross-level interaction) to the final model (including the cross-level interaction). Since the analyses resulted in a large total amount of specified models (multiple well-being measures x 6 studies), detailed results are reported in the supplement. The relevant parameters of the cross-level interactions (well-being moderating affective reactivity to positive events, γ_{21}), our main interest in, are reported in detail. In order to increase comparability across studies – and in the absence of meta-analytic tools for coefficients from multilevel models – we additionally calculated correlations of well-being indicators with the person-specific reactivity slopes. For this purpose, we specified affective reactivity models without Level-2 variables (i.e., no well-being indicators) and estimated person-specific slopes. These person-specific estimates reflect each person's affective reactivity to positive events. We correlated these estimates with all global well-being indicators. These correlations give another approximation to a standardized measure of effect and were used to display our results graphically.

Results

Descriptive information (means and standard deviations) for each study and Level-2 well-being indicator is provided in Table 1 in the supplement (due to the large amount of information). Regarding affective reactivity, participants experienced reliably higher PA and lower NA on occasions with a positive event, compared to occasions without a positive event, in Studies 1, 2, 3, and 6. In Studies 4 and 5, PA increased, and NA decreased significantly, as the perceived intensity of positive

events increased (see Table 2 in supplement). Additionally, there was a main effect of global well-being. That is, higher global well-being, as indicated by either high scores on the well-being composite scores or positive indicators (SWL, Trait PA, Aggregated PA), or low scores on negative indicators of well-being (CES-D, Trait NA, and Aggregated NA), respectively, predicted higher levels of PA and lower NA in daily life in all studies (for a few exceptions in Study 6, see Table 2 in supplement). Within each study, positive indicators of global well-being correlated positively with each other and negatively with negative indicators of global well-being (with a few exceptions in Studies 4 and 6, please see Table 2).

In the following, we will report in detail how the well-being composite scores moderate positive event reactivity (i.e., increases in PA and NA at occasions on which individuals reported a positive event). With this focus on the composite scores, we mean to condense and simplify the emerging pattern of moderation effects. This is followed by a brief summary of how the individual well-being indicators moderate positive event reactivity (first for positive indicators, then negative indicators). In Tables 3 and 4, we report the moderating effects for well-being on the within-person relationship between positive events and momentary affect. That is, we only report the estimates for the parameter γ_{21} that indicate the cross-level interaction (i.e., whether global well-being at Level-2 interacts with positive events at Level-1 in the prediction of PA and NA). We also report the Pseudo-R^2 statistics for these cross-level interactions in Tables 3 and 4, respectively. For a complete report of all specified models, please see Table 2 in the supplement.

Table 2.

Correlations Between Global Well-Being Indicators in Each Study

Study 1

WB indicator	1	2	3	4	5
1. SWL					
2. Trait PA	**.51****				
3. CES-D	**-.41****	**-.37***			
4. Trait NA	**-.34***	**-.59***	**.56****		
5. Agg. PA	**.42****	**.47****	**-.44****	**-.38***	
6. Agg. NA	**-.35***	**-.35***	**.58****	**.43****	**-.46****

Study 2

	1	2	3	4	5
1. SWL					
2. Trait PA	-				
3. CES-D	-	-			
4. Trait NA	-	-	-		
5. Agg. PA	**.47****	-	-	-	
6. Agg. NA	**-.31****	-	-	-	**-.43****

Study 3

WB indicator	1	2	3	4	5
1. SWL					
2. Trait PA	**.55****				
3. CES-D	**-.60****	**-.42****			
4. Trait NA	**-.63****	**.70****	**.70****		
5. Agg. PA	**.53****	**-.52****	**-.60****	**-.58****	

Study 4

	1	2	3	4	5
1. SWL					
2. Trait PA	**.42****				
3. CES-D	**-.54****	**-.42****			
4. Trait NA	**-.31****	-.13	**.50****		
5. Agg. PA	**.39****	**.32****	**-.45****	**-.27****	

6. Agg. NA	**-.56****	**.39****	**.62****	**.63****	**-.62****	6. Agg. NA	**-.29****	**-.15***	**.42****	**.51****	**-.43****

	Study 5						**Study 6**				
WB indicator	1	2	3	4	5		1	2	3	4	5
1. SWL						1. SWL					
2. Trait PA	**.67****					2. Trait PA	**.37****				
3. CES-D	-	-				3. CES-D	**-.41***	**-.39****			
4. Trait NA	**-.46****	**-.44****	-			4. Trait NA	**-.32***	.04	**.35****		
5. Agg. PA	**.30***	**.52****	**-.3***			5. Agg. PA	**.34****	**.34****	**-.24****	-.13	
6. Agg. NA	-	-	-	-	-	6. Agg. NA	**-.20***	**-.17***	**.40***	**.33****	.11

Note. WB = Well-being; PA = positive affect; NA = negative affect; SWL = Satisfaction with Life Scale; CES-D = Center for Epidemiologic Studies Depression Scale; Agg. = Aggregated

* $p < .05$ ** $p < .001$.

PA as outcome variable; well-being composite score at trait level. Results for the moderation effects and PA as an outcome variable are summarized in Table 3. As shown, the well-being composite score was a significant moderator in three of the six studies (Studies 2, 3, and 4). Specifically, higher well-being composite scores were related to smaller increases in PA in reaction to positive events in these studies. Pseudo-R^2 statistics indicated that the well-being composite scores, when significant, accounted for 8 – 25% of the individual differences in affective reactivity to positive events.

The correlations between the well-being composite scores and the person-specific estimates were in line with the cross-level interactions from the multilevel models. That is, these correlations between the well-being composite scores and the person-specific estimates of the within-person association between positive events and PA were negative (Figure 1a). Together, higher scores on these well-being composite scores were associated with decreased within-person affective reactivity.

NA as outcome variable; well-being composite score at trait level. Results for the moderation effects and NA as an outcome variable are summarized in Table 4. For NA as an outcome variable, the well-being composite score moderated affective reactivity to positive events in four of the six studies (Studies 1, 2, 3, and 4). In these studies, higher well-being composite scores predicted smaller decreases in NA in reaction to positive events. Pseudo-R^2 statistics indicated that the well-being composite scores accounted for 16 – 37% of the individual differences in affective reactivity to positive events in these studies.

The correlations between the well-being indicators and the person-specific estimates were in line with these results. The well-being composite score yielded positive correlations with the person-specific estimates of the within-person association between positive events and NA (Figure 1a). This again indicates that higher scores on these well-being composite scores correlate with smaller within-person associations.

Table 3.

Cross-Level Interactions Between Global Well-Being Indicators and Within-Person Associations Between Positive Events and PA

	Study 1			**Study 2**			**Study 3**			**Study 4**			**Study 5**			**Study 6**		
WB indicator	L-2 × L-1	*SE*	Pseudo -R^2 (%)	L-2 × L-1	*SE*	Pseudo -R^2 (%)	L-2 × L-1	*SE*	Pseudo -R^2 (%)	L-2 × L-1	*SE*	Pseudo -R^2 (%)	L-2 × L-1	*SE*	Pseudo -R^2 (%)	L-2 × L-1	*SE*	Pseudo -R^2 (%)
SWL	-0.08	0.04	4.8	**-0.11***	0.04	16.9	**-2.24***	0.69	14.0	**-0.02***	0.01	6.3	-0.02	0.02	0.4	-0.02	0.02	2.9
Trait PA	**-0.24***	0.08	25.8	-		-	-1.83	1.57	-0.1	-0.02	0.01	0.6	-0.03	0.03	-1.8	-0.01	0.03	-1.7
CES-D	0.06	0.08	-1.5	-	-	-	**4.02***	1.88	6.6	**0.05***	0.02	3.9	-	-	-	0.10	0.07	3.7
Trait NA	0.09	0.07	3.5	-	-	-	**4.16***	1.43	12.1	**0.04***	0.01	5.3	0.03	0.03	0.4	0.03	0.02	5.9
Agg. PA	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Agg. NA	0.03	0.05	-1.4	**0.29***	0.12	14.7	**0.19***	0.08	8.1	**0.003***	0.00	6.9	-	-	-	**0.04***	0.02	3.5
WB composite score	-0.20	0.31	1.39	**-0.22****	0.06	25.21	**-2.68****	0.87	13.54	**-0.03****	0.01	8.25	-0.003	0.01	-6.83	-0.02	0.49	0.47

Note. WB = Well-being; L-2 × L-1 = Level-2 – Level-1 Interaction; PA = positive affect; NA = negative affect; SWL = Satisfaction with Life Scale; CES-D = Center for Epidemiologic Studies Depression Scale; Agg. = Aggregated. Aggregated PA was not included as a Level-2 predictor for momentary PA, and not included in the WB composite score, due to statistical dependence between the outcome and independent variable. * $p < .05$ ** $p < .001$

Table 4.

Cross-Level Interactions Between Global Well-Being Indicators and Within-Person Associations Between Positive Events and NA

	Study 1			**Study 2**			**Study 3**			**Study 4**			**Study 5**			**Study 6**		
WB indicator	L-2 × L-1	*SE*	Pseudo -R^2 (%)	L-2 × L-1	*SE*	Pseudo -R^2 (%)	L-2 × L-1	*SE*	Pseudo -R^2 (%)	L-2 × L-1	*SE*	Pseudo -R^2 (%)	L-2 × L-1	*SE*	Pseudo -R^2 (%)	L-2 × L-1	*SE*	Pseudo -R^2 (%)
SWL	**0.14****	0.04	17.5	0.05	0.03	3.3	**1.85****	0.40	26.7	**0.02****	0.01	9.7	-	-	-	-0.03	0.02	-0.61
Trait PA	**0.27****	0.08	17.7	-	-	-	1.13	0.94	0.4	0.02	0.01	1.17	-	-	-	0.01	0.02	-3.8
CES-D	**-0.29****	0.07	30.3	-	-	-	**-4.96****	1.04	29.2	**-0.05****	0.01	8.4	-	-	-	-0.09	0.07	5.4
Trait NA	**-0.15***	0.07	5.7	-	-	-	**-4.64****	0.77	42.5	**-0.04****	0.01	13.9	-	-	-	0.02	0.02	0.68
													-	-	-	-	-	-
Agg. PA	**0.21****	0.06	17.4	**0.19***	0.06	23.9	**0.17****	0.04	24.8	**0.002****	0.002	11.2	-	-	-	-0.05	0.03	1.29
Agg. NA	-	-	-	-	-	-	-		-	-		-	-	-	-	-	-	-
WB composite score	**0.21****	0.04	32.23	**0.11***	0.05	16.22	**2.69****	0.49	37.39	**0.02****	0.01	17.32				-0.02	0.03	-2.28

Note. WB = Well-being; L-2 × L-1 = Level-2 – Level-1 Interaction; PA = positive affect; NA = negative affect; SWL = Satisfaction with Life Scale; CES-D = Center for Epidemiologic Studies Depression Scale; Agg. = Aggregated. Aggregated PA was not included as a Level-2 predictor for momentary PA, and not included in the WB composite score, due to statistical dependence between the outcome and independent variable. * $p < .05$ ** $p < .001$

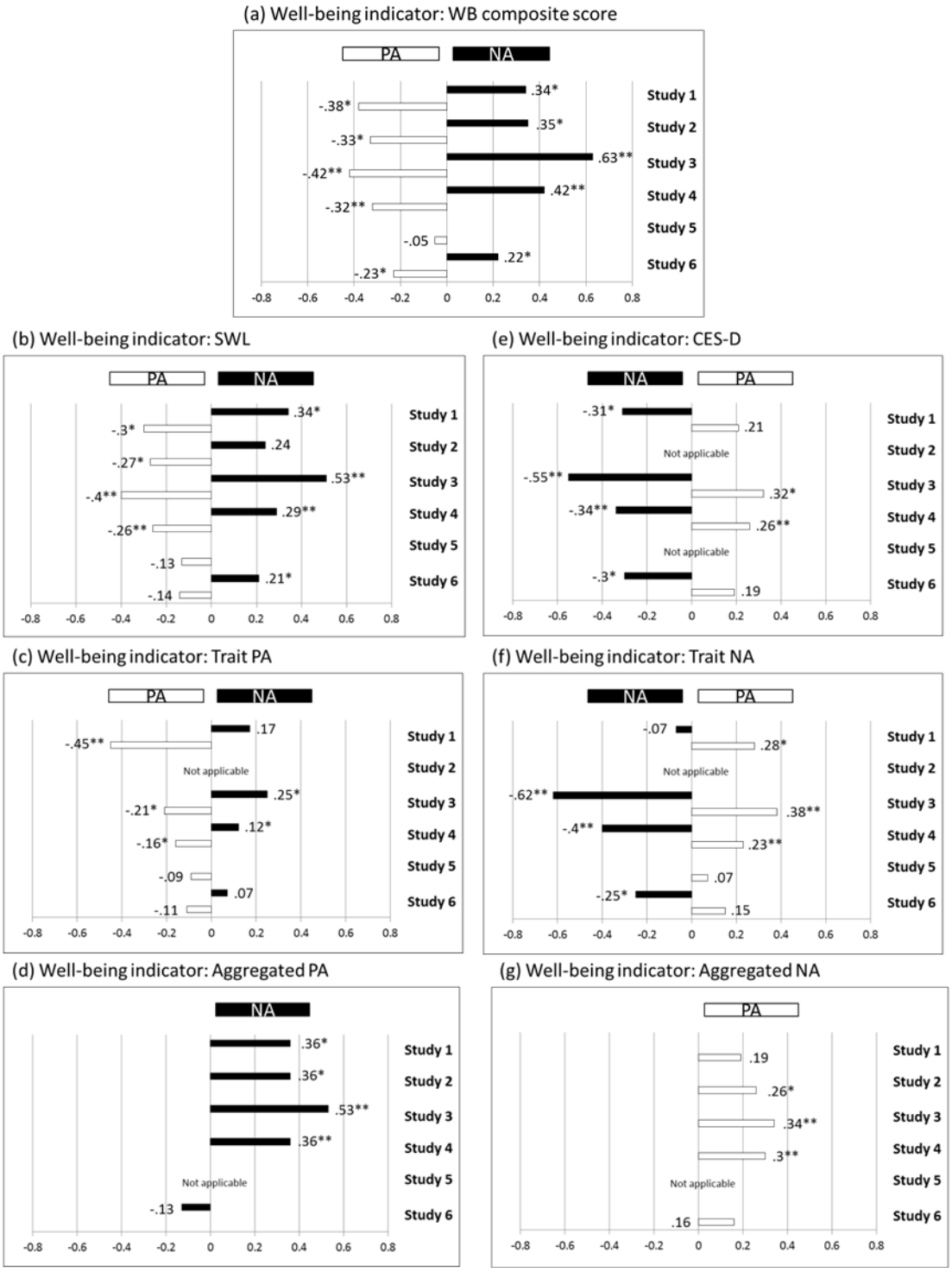

Figure 1. Correlations between global well-being indicators and person-specific reactivity slopes. Higher scores on positive indicators of well-being (SWL, Trait PA, Aggregated PA, and WB composite score) yield negative and positive correlations with the PA and NA slopes (a – d), while lower scores on negative indicators of well-being (CES-D, Trait NA, Aggregated NA) yield positive and negative correlations with the PA and NA slopes (e – g). These correlations thus indicate a lower affective reactivity to positive events.

Note. WB = well-being; PA = positive affect; NA = negative affect; SWL = Satisfaction with Life Scale; CES-D = Center for Epidemiologic Studies Depression Scale. * $p < .05$ ** $p < .001$

PA as outcome variable; positive and negative indicators of global well-being at trait level. Results for the moderation effect of each of the global well-being indicators on affective reactivity with PA as an outcome variable can be found in Table 3. In summary, higher global well-being, as indicated by higher scores on positive indicators of global well-being (SWL and Trait PA) as well as lower scores on negative indicators of global well-being (CESD-D, Trait NA and Aggregated NA) predicted smaller increases in PA across five of the six studies (Studies 1, 2, 3, 4, and 6) at occasions with positive events. As indicated in Table 3, 12 out of 22 of these interaction effects in these five studies reached significance. Pseudo-R^2 statistics indicated that the well-being indicators, when significant, accounted for 4 – 26% of the individual differences in affective reactivity to positive events.

The negative and positive correlations between the reactivity estimates and the positive and negative trait measures also indicate that higher global well-being is associated with decreased affective reactivity (Figures 1b – g).

NA as outcome variable; positive and negative indicators of global well-being at trait level. Positive and negative indicators of global well-being also moderated affective reactivity to positive events with NA as an outcome variable, as shown in Table 4. In summary, higher global well-being, as indicated by higher scores on positive indicators of global well-being (SWL, Trait PA and Aggregated PA) and lower scores on negative indicators of global well-being (CESD-D and Trait NA) predicted again smaller decreases in NA across four of the six studies (Studies 1, 2, 3, and 4). As indicated in Table 4, 14 out of 17 of these interaction effects in these four studies reached significance. Trait measures in these studies accounted for 6 – 43% of the individual differences in affective reactivity to positive events. Again, the positive and negative correlations between the reactivity estimates and the positive and negative global well-being indicators indicate that higher global well-being correlates with smaller within-person associations.

Together, these results show that across the six studies, we found various significant moderation effects of global well-being on the affective reactivity to positive events. All significant effects showed that higher global well-being was associated with reduced affective reactivity to

positive events. When looking at the pattern of the results per study, we found that in four of the six studies (Studies 1, 2, 3, and 4) the majority of the tested effects were significant, with all of them predicting reduced affective reactivity to positive events for higher global well-being. Two studies (Studies 5 and 6) do not follow this pattern, with few to no significant effects.

Discussion

The central aim of the present study was to test whether higher levels of global well-being are associated with enhanced or reduced affective reactivity to positive events in daily life, the latter being in line with recent research on emotion dynamics and well-being. We found that individuals with higher levels of global well-being are characterized by decreased reactivity to positive events. More specifically, in four of six studies we found that in the majority of the tested effects, individuals with higher global well-being showed smaller decreases in momentary negative affect and in some instances also smaller increases in momentary positive affect in reaction to positive events. We found these effects for positive and negative indicators of global well-being, as well as well-being composite scores. The inclusion of these various global well-being indicators and two different outcome variables (positive and negative affect) across six studies is a major extension of previous research. Moreover, the significant moderation effects we found for the well-being composite scores nicely summarize the overall picture that was gained from the analyses with the individual well-being indicators, and in one study they even show the moderation effect more clearly (Study 2). As the well-being composite scores encompass both positive and negative well-being indicators, they add to the strength and generalizability of our results and underline the importance of global well-being as a moderator of the within-person relationship between positive events and momentary affective experiences.

Reduced Affective Reactivity for Both Positive and Negative Affect

In the present study we found reduced affective reactivity to positive events for individuals with higher global well-being. This effect became apparent in smaller decreases in negative affect, and additionally, though only in some of the studies, in smaller increases in positive affect in light of positive events. The relatively consistent pattern of findings for negative affect as an outcome variable is in line with results from clinical studies. Here, individuals with lower well-being (one major

characteristic of those with major depressive disorder or depressive symptoms) showed greater decreases in negative affect in reaction to positive events (Bylsma et al., 2011; Peeters et al., 2003). Specifically, the greater decreases in negative affect suggest that positive events not only bring joy into our lives. They might just as well ameliorate our negative affect. This might be of particular importance for individuals with lower levels of global well-being that have higher baseline levels of negative affect. Contrary, individuals with higher global well-being might not have the same need to improve their levels of negative affect, potentially explaining their comparatively small decreases in negative affect in response to positive events in our study. The idea that positive events may be used to dampen negative affect also fits in with the idea that positive emotions may accelerate recovery from negative emotions (Fredrickson & Levenson, 1998). It is also in line with different studies that stress the adaptive function of positive emotions in times of stress (e.g., Ong, Bergeman, Bisconti, & Wallace, 2006).

Other than expected, well-being did not moderate affective reactivity in Study 5, and the evidence for moderation was scarce in Study 6. There are some methodological differences between these and the other studies that might explain the differences in findings. First, in Study 5, bipolar affect items, representing overall momentary affect, were used instead of distinct measures of positive or negative affect. This less differentiated measurement of affect might have blunted an effect on either of the two affect valences. Second, Study 6 clearly diverges with respect to the time scale covered. The time interval between occasions was days and not hours as in the other studies. As a consequence it might be that other negative events occurred during the day and had interfered with the reactivity to positive events investigated in this study.

Present Findings and Emotional Stability

The present results are in line with various theoretical accounts and prior empirical findings. One such finding is that higher emotional stability of negative and, to a lesser extent, also positive affect, is related to higher levels of well-being (Houben et al., 2015). Yet, these authors' meta-analysis did not consider affective reactivity in their study of emotional stability. Thus, our findings seem to complement these prior insights on emotional stability and well-being, perhaps even in a way that may

initially seem counterintuitive: Even in the presence of positive events, emotional stability—in the sense of decreased responding—is related to higher levels of well-being. That is, less fluctuation in momentary positive and negative affect, reflected in various indicators including affective reactivity, seems to be a pervasive characteristic of people with higher levels of well-being. However, while our results suggest that reduced affective reactivity is characteristic of individuals with higher levels of well-being, we do not assume that individuals have reached such higher levels of well-being *because* of their reduced reactivity—an issue that we will discuss below.

Even though our results align with the importance of emotional stability for global well-being, they somewhat contradict the idea that responding flexibly to changing emotional contexts is linked to adaptive functioning and psychological health (Kashdan & Rottenberg, 2010). For example, flexibly adjusting one's emotional responses to changing emotional stimuli in the laboratory is associated with higher trait resilience (Waugh, Thompson, & Gotlib, 2011), an indicator related to higher global well-being. Relatedly, inflexible responding may be indicative of some manifestations of psychopathology, such as context insensitivity in major depressive disorder (Rottenberg, 2005). Therefore, responding to positive events in daily life would be deemed an adaptive response according to the flexibility view. At first glance, this seems to contradict the present findings. However, one needs to be careful when drawing such conclusions. As we investigated affective reactivity to real life events through the experience-sampling and daily diary method, we cannot control for the type of events reported, making it difficult to define the level of appropriateness or inappropriateness of an emotional response. It would therefore be possible that the observed smaller affective reactions in individuals with higher well-being reflect more adjusted responses. Furthermore, it could be that people with higher levels of well-being respond more flexibly to changes in the valence of emotional significant events. Thus, a higher flexibility does not become apparent in strong reactions, but rather in a quick adaptation to variations in positive and negative events in daily life.

No Evidence for Enhanced Affective Reactivity

None of the associations in our study were in in favor of the proposition of enhanced affective reactivity to positive events in people with higher global well-being. One explanation for this may be

that further increases in positive and decreases in negative affect when something positive occurs are merely more difficult to accomplish, as these individuals with higher global well-being already have high levels of positive and low levels of negative affect, respectively. That is, the potency of positive events seems to diminish toward highest levels of well-being. Importantly, those individuals with highest levels of well-being neither reached the ceiling of the scale measuring positive affect, nor did they reach the floor of the scale measuring negative affect. Furthermore, many observations go into the estimation of affective reactivity as measured in individuals with different levels of global well-being (i.e., the number of occasions in each study). This diminishes the biasing effects of extreme scores on the reactivity estimates (i.e., the error components in the reactivity estimates should be low). This, in turn, reduces the likelihood that the observed results are due to regression to the mean.

When viewed from the perspective of the savoring proposition, the findings of our study are indeed surprising. One possible explanation might be that individuals with higher well-being derive greater benefits in terms of well-being by savoring greater life events rather than small everyday events. For example, reminiscing about the past (one of multiple savoring strategies; Bryant, 2003) might prolong the positive emotional experience of these events, by keeping the memory of such events alive. Future studies with a focus on savoring positive life events would be able to shed light on this possibility.

The present findings also diverged from other research in favor of enhanced affective reactivity in people with higher levels of well-being, in particular personality and clinical research (e.g. Bylsma et al., 2008; Gross et al., 1998). Notably, findings from both bodies of research were mainly based on laboratory studies, which could partly explain the difference in findings. For example, people with lower levels of well-being (e.g., people depressed people) are potentially less motivated to attend to the standardized stimuli that are usually used in laboratory settings, while in daily life the greater emotional relevance might foster their motivation to attend to the events they experience. However, to disentangle such context effects, future studies need to investigate affective reactivity in the laboratory and in daily life within the same individuals (see Koval et al., 2015, for such multimethod approaches).

Limitations and Future Directions

While one strength of the present study is the investigation of affective reactivity to positive events and global well-being across several studies and with various global well-being indicators, one noteworthy limitation is that to our knowledge, there is no established procedure for meta-analyzing cross-level interaction effects from multilevel analyses. We tried to confront this shortcoming by computing well-being composite scores through principal-component analyses, and by including these as well-being moderator variables in our analyses. Nevertheless, such a meta-analytic approach would have enhanced claims about reliability and the size of the found effects. Establishing such a procedure would be highly valuable for future studies dealing with similar data.

Our results suggest that individuals with higher well-being are characterized by reduced affective reactivity to positive events. This relationship, as investigated in the current study, is purely correlational and does not allow for any conclusions regarding the direction of the effects. If we were to speculate about causal relationships among the different variables and about their potential developmental trajectories, the following more long-term dynamics seem possible. In periods of lower well-being, for example after the experience of a negative life event or during recovery from a depressive episode, daily positive events may gain in importance in the sense of brightening one's mood. Such enhanced affective reactivity in periods of low well-being may, in the longer term, even lead to increases in well-being. The more one generally recovers from a negative life event or a depressive episode, the more positive events lose importance for general well-being—a decoupling occurs and well-being is no longer as contingent on positive events as it was during the recovery period. Recent findings on the long-term coupling of neuroticism and affective reactivity to negative events could be interpreted as being in accordance with this view (Howland, Armeli, Feinn, & Tennen, 2017). Here, the strength of affective reactions to negative events as approached with experience sampling varied from year to year, and it became stronger as neuroticism and overall stress increased. That is, affective reactivity was also dynamic across a longer time scale in this study, and it was also related to global individual difference variables.

Another limitation pertains to the assessment of our positive event variable. Positive events were measured differently in two of our studies, namely using intensity ratings (Studies 4 and 5) instead of dichotomous items. Decreased reactivity for individuals with higher global well-being as found in Study 4 yields a slightly different interpretation in comparison to the studies with dichotomous event variables. While affective reactions generally increased as a function of stimulus intensity in this study as to be expected from the literature (see Table 2 in the supplement; cf. Larsen & Diener, 1987), individuals with higher global well-being actually show less such proportional increase. On the one hand, this reduces comparability across studies, but on the other hand, it shows that the observed differences in affective reactivity cannot be ascribed to differences in event intensity.

Finally, as each study involves the re-analysis of existing data, it was not possible to do a-priori power analyses to determine sample sizes needed to appropriately power the present research question. Nevertheless, we observed comparable effects in the study with the smallest (Study 1, N = 70, number of occasions = 54) and the largest sample (Study 4, N = 200, number of occasions = 61). It thus seems that the different studies had sufficient power to observe the effects under investigation.

Conclusions

In summary, in the majority of our studies we found that higher levels of global well-being were associated with a reduced affective reactivity to positive events, in line with recent research on emotion dynamics and well-being. These results show that, even in the presence of positive events, less fluctuation in the experiences of positive and negative affect seem to be a defining characteristic of people with higher global well-being. Nevertheless, everyday positive events are part of daily life, and especially for individuals with lower global well-being, they seem to be a meaningful way to brighten one's momentary mood.

10 General Discussion

With the work in this dissertation I sought to contribute to answering the question of why some people are happier than others. With this in mind, the aim of this dissertation was to get a better understanding of subjective well-being – one commonly used scientific concept of happiness. Empirically, I approached this aim by investigating the affective processes – affective reactivity and emotion regulation – underlying short-term changes in positive affective experiences and their potential link to interindividual differences in subjective well-being. I initially presented two different lines of research that motivated this empirical approach. The first line of research provides a rationale for the study of positive emotions as a constituent element of subjective well-being, by positing that intense positive affective experiences are particularly beneficial for higher levels of subjective well-being (Bryant & Veroff, 2007; Fredrickson, 2001). The second line of research emphasizes the importance of studying people's changing affective experiences and behaviors, as these, over time, may impact the development of more stable emotional outcomes, such as subjective well-being (Wichers, 2014; Hollenstein et al., 2013). Specific research questions were addressed in three empirical studies that included investigations at the subjective and neural level as well as in the laboratory and in daily life. These research questions concerned (1) whether enhanced affective reactions to positive stimuli and greater increases in affect when up-regulating positive emotions, as measured in the laboratory, relate to higher subjective well-being, (2) which brain regions underlie within-person changes in positive affective experiences when up-regulating positive emotions, and (3) whether enhanced or reduced affective reactivity to positive events in daily life relates to higher subjective well-being.

Major findings of each study are briefly summarized in Table 1. In the following, I will integrate these findings and discuss their contribution to the literature. I will focus on the overall picture that emerged in this dissertation of how affective reactivity and the up-regulation of positive emotions can be characterized at the subjective and neural level and how they relate to interindividual differences in subjective well-being. Finally, I will elaborate on limitations and potential implications for future research.

Table 1
Summary of the Papers Contributing to this Dissertation

Aims	Findings	Conclusion
Paper I: Examine the relation between the successful up-regulation of positive emotions (as indicated by a performance-based measure), habitual up-regulation of positive emotions and subjective well-being.	Up-regulating, as compared to reacting to positive film clips, did not significantly increase positive affect – likely due to the specific experimental design and particularly strong increases in positive affect in the reactivity condition. Successful up-regulation of positive emotions was not significantly associated with trait emotion regulation. Further, only greater habitual, but not more success in up-regulating positive emotions seems to be related to higher subjective well-being.	These findings show that people who up-regulate their positive emotions more frequently are not necessarily more successful at it, and only the former seems to be positively associated with subjective well-being. They furthermore point towards differences in performance-based and self-reported measures of emotion regulation.
Paper II: Investigate the neural correlates underlying the experience of affect during the up-regulation of positive emotions and relate them to emotion regulation and affect in daily life.	Increased activation in the ventral striatum (VS) was related to between- and within-person differences in affect during the up-regulation of positive emotions in the laboratory, but not when up-regulating in daily life. Further, increases in positive affect were associated with increased activation in medial frontal and subcortical emotion-related brain regions (including the VS) and decreased activation in a fronto-parietal control network. The lower participant's overall affect in daily life, the stronger the involvement of these emotion-related brain regions when enhancing affect in the laboratory.	This study highlights the role of the VS in the up-regulation of positive emotions by showing that it is not only activated across contexts, but also reflects more transient changes in affect within individuals. The findings further suggest that enhancing one's positive emotions might rely less on cognitive control processes than other forms of emotion regulation (e.g., the down-regulation of negative emotions). Finally, the study underlines the importance of including measures from both the laboratory and daily life in the study of emotion.
Paper III: Provide a large-scale and systematic test of whether people with higher global well-being have enhanced or reduced affective reactions to positive events in daily life.	Across six experience-sampling and daily diary studies, higher global well-being (as measured with various positive and negative indicators as well as a well-being composite score) was related to smaller decreases in negative and in some studies also smaller increases in positive affect in response to positive events.	These findings show that for people with lower global well-being, positive events might be an effective way to brighten their momentary mood. Further, adding to previous research, they indicate that even in the presence of a positive event, less fluctuation in positive and negative affect seems to be a characteristic of higher subjective well-being.

10.1 Affective Reactivity, Emotion Regulation and Subjective Well-Being

In the present dissertation I investigated the relation between affective reactivity, emotion regulation and interindividual differences in subjective well-being. Regarding affective reactivity, I tested the two opposing predictions of whether enhanced or reduced affective reactivity to positive events relate to higher subjective well-being. In respect to the up-regulation of positive emotions, I hypothesized greater increases in affect, when up-regulating positive emotions, to relate to higher subjective well-being. Across all studies, results showed that positive events and stimuli reliably elicited affective reactions and that these can be further increased through the deliberate up-regulation of positive emotions (for one exception see *Paper I*, and for a discussion thereof see 10.3). However, I did not find evidence for a link between enhanced affective reactivity to positive events or stimuli and higher subjective well-being or greater success in up-regulating positive emotions and higher subjective well-being in any of the studies. In one study, evidence was even found for the opposite: Higher subjective well-being was related to *reduced* affective reactivity to positive events in daily life (Grosse Rueschkamp et al., 2018). The overall picture that emerged in this dissertation therefore seems to speak against the idea that maximizing positive experiences implicitly (through enhanced affective reactivity) or explicitly (through the up-regulation of positive emotions) relates to higher subjective well-being.

These findings seem to contradict theoretical work from positive psychology that stresses the beneficial effects of intense positive affective experiences for subjective well-being. The broaden-and-build theory, for example, posits that positive emotions broaden people's attention and thinking in ways that lead to increased personal resources and ultimately increased subjective well-being. Moreover, the savoring account suggests the process by which people derive joy from the positive experiences in their life – termed savoring – to be one of the mechanisms underlying higher levels of subjective well-being. Besides this emphasis on the importance of intense positive affective experiences for subjective well-being, the findings in this dissertation suggest that these do not seem to weigh much in the overall composition of subjective well-being. Instead, people with higher subjective well-being seem to even have reduced affective reactions to positive events in daily life

(Grosse Rueschkamp et al., 2018). This finding of reduced affective reactivity in people with higher subjective well-being aligns with empirical and theoretical work from research on affect dynamics. For example, one study showed that smaller increases in positive affect in response to daily positive events were related to higher life satisfaction (Oishi et al., 2007). The authors argued that people with higher levels of subjective well-being pay less attention to a single positive event as they frequently experience positive events, leading to a habituation process. The finding of reduced affective reactivity in people with higher subjective well-being also fits into the picture of greater overall emotional stability and higher well-being, as found in a meta-analysis on affect dynamics (Houben et al., 2015). The finding in this dissertation complements the findings reported in this meta-analysis: Even in the presence of positive events, is more stability in positive and negative affect (as indicated by decreased affective reactivity) related to higher subjective well-being.

While I found affective reactivity to positive events to be reduced in people with higher subjective well-being in one study (Grosse Rueschkamp et al., 2018), no such association was found in the laboratory (*Paper I*) and no significant association – in either direction – was found between the successful up-regulation of positive emotions (i.e., greater increases in positive affect when up-regulating) and subjective well-being (*Paper I*). One possible explanation for why no significant link was found between the affective processes and subjective well-being in the laboratory may be the method that was used to generate these findings. For example, in the laboratory, affective experiences are induced artificially through standardized stimuli, while in daily life these emerge naturally in response to personal events people experience in their lives. The smaller significance of the standardized stimuli in the laboratory might have dampened people's motivation to further enhance their feelings. Thus, besides their potential greater capacity to up-regulate positive emotions, people with higher subjective well-being might not have engaged in up-regulation efforts to a full extent (for a detailed discussion on differences in findings across laboratory and daily life methods, see 10.5). Hence, it seems possible that a relation between the successful up-regulation of positive emotions and subjective well-being would have become evident when measured in daily life.

However, given the overall picture that emerged in this dissertation (i.e., no evidence for a role of intense positive affective experiences in higher subjective well-being) it seems rather unlikely that

greater success in up-regulating positive emotions in daily life is related to higher subjective well-being.

Alternatively, it could be that in contrast to successfully up-regulating positive emotions, as assessed in the present dissertation, rather the *flexible* regulation of one's positive emotions is central to subjective well-being. Flexibility in general has been defined as the capacity to shift affect and behavior in response to changing events or contextual demands (Hollenstein et al., 2013) and has been deemed essential for adaptive functioning and well-being (Kashdan & Rottenberg, 2010). Regulatory flexibility in particular, is thought to encompass the flexible use of different regulation strategies in accordance with one's changing goals (Bonanno & Burton, 2013) and the flexible engagement in regulatory efforts based on the specific situation at hand (Blanke et al., 2019). Such regulatory flexibility might be of relevance for the up-regulation of positive emotions. It has been proposed that the efficiency of specific up-regulation strategies depends on the strength of one's initial affective reaction, that is, the intensity of the affective experience to be regulated. For example, directing one's attention to the present moment is thought to be more efficient when the experience to be regulated is rather intense, compared to when the situation is only mildly positive (Quoidbach, Mikolajczak, & Gross, 2015). Thus, the capacity to flexibly select the most efficient up-regulation strategy could reflect one component of regulatory flexibility in respect to the up-regulation of positive emotions. Alternatively, knowing when it is most beneficial to up-regulate one's positive experiences might also be an important component of the flexible regulation of positive emotions. Savoring positive experiences, for example, has been shown to have the greatest impact on current affect when one only experiences few positive events (Jose, Lim, & Bryant, 2012, see also 10.3). Together, flexible strategy selection or flexible engagement in up-regulatory efforts might constitute an important aspect of the relation between the up-regulation of positive emotions and subjective well-being.

In sum, the overall picture that emerged in this dissertation emphasizes the importance of taking dynamic aspects into account when aiming to understand the role of positive affective experiences in subjective well-being: Not the experience of intense positive affective experiences in the context of positive events, but rather less fluctuation in positive affect seems to be a defining characteristic of people with higher subjective well-being.

10.2 Neural Responses Underlying Changes in Positive Affective Experiences

The aim of the present dissertation was to get a better understanding of interindividual differences in subjective well-being by investigating affective reactivity and emotion regulation as they unfold within individuals over time. This dynamic approach was substantiated at the neural level by an investigation of the neural correlates underlying within-person changes in positive affective experiences when reacting to positive stimuli or up-regulating positive emotions (*Paper II*). Focusing primarily on the up-regulation process, the findings showed that engaging in the up-regulation of positive emotions increased activation in the ventral striatum (VS), a subcortical region previously associated with positive affective processing (e.g., Vrtička et al., 2008), and this activation relates to within-person (i.e., trial-to-trial) changes in momentary affect. Thus, the strength of VS recruitment can serve as a neural indicator of the successful up-regulation of positive emotions, as indicated by increases in positive affect when up-regulating in laboratory settings. This finding further demonstrates that the previously found link between VS activity and between-person differences in affect when up-regulating positive emotions (Greening et al., 2014) also holds at the within-person level. For a discussion of the relation between VS activity during the up-regulation of positive emotions and changes in affect when up-regulating in daily life, see 10.5.

Additionally, within-person changes in positive affective experiences (across both affective reactivity and emotion regulation) were related to increased activation in a "core-set" of medial frontal and subcortical emotion-related brain regions. This set comprised, next to the VS, regions such as the amygdala, the hippocampus, and the ventromedial prefrontal cortex, which have previously been implicated in emotion-related processing (e.g., the amygdala in the detection of threat; Phelps & LeDoux, 2005). This pattern of neural activation fits with recent brain models of emotion that suggest affect to be reflected in brain networks rather than in single regions that operate in a valence-dependent fashion (e.g., the VS or the amygdala; Berridge, 2019; Lindquist, Satpute, Wager, Weber, & Barrett, 2016). For instance, the "affective workspace" hypothesis posits that both positive and negative affective experiences rely on a flexible network of brain regions, which is implicated in affective processing more generally (Lindquist et al., 2016). Similarly, the "affective modes" hypothesis states that neural "modules" (e.g., brain regions or neurotransmitter systems) are not

permanently related to specific affective functions (e.g., processing of threat or reward in the amygdala and VS, respectively) but that these functions are subject to change, as conditions or affective states change (Berridge, 2019). Both models therefore assume distributed patterns of neural activity across networks to represent different affective states (Kragel & LaBar, 2016). The current findings add to this, by showing that not only the VS, but patterns of neural activity across an emotion-related network of brain regions change with increases in positive affective experiences.

Alongside, I found within-person changes in positive affective experiences to be also associated with relative *deactivation* in a fronto-parietal network (including lateral parietal and medial, as well as lateral prefrontal cortices). This fronto-parietal network has been shown active during inhibition and control processes for the down-regulation of negative emotions (e.g., Etkin et al., 2015; Ochsner et al., 2012). The present finding therefore could suggest that enhancing positive affective experiences – in contrast to reducing negative affective experiences – might rely more on the capacity to "suppress" these control functions to "allow more" of one's (positive) affective experiences. This interpretation is in line with the mechanisms thought to underlie the up-regulation of positive emotions. In contrast to the down-regulation of negative emotions, during which affective reactions and regulatory processes are competing (Sheppes & Gross, 2011), affective reactions and regulatory processes are thought to reinforce each other during the up-regulation of positive emotions (Jose et al., 2012). Hence, when up-regulating positive emotions, an already existing affective experience is further intensified and regulatory efforts are suggested to be inversely proportional to the intensity of the affective experience to be regulated (Quoidbach et al., 2015). In other words, when one has strong positive affective reactions, subsequent up-regulation should be comparable easy and effortless, while rather mild positive (or negative) affective reactions should require greater regulation efforts – and greater recruitment of this fronto-parietal control network.

Taken together, the present findings at the neural level complement the dynamic approach of this dissertation, by showing that activation in the VS not only reflects the general capacity to (up-) regulate positive emotions, but also dynamic affective responses that are observable within individuals. Additionally, changes in positive affective experiences during affective reactivity and the up-regulation of positive emotions are mirrored by the neural responses in a set of emotion-related

brain regions and the fronto-parietal control network – with increased and decreased activation, respectively. The latter finding indicates that the neural mechanisms underlying changes in people's positive affective states may be different from those underlying changes in negative affect.

One finding in the present dissertation may even provide an indication for a possible link between the neural correlates of positive affective experiences, as identified in the present dissertation, and interindividual differences in subjective well-being. People with lower daily affect (an indicator of lower subjective well-being) enaged the emotion-related brain regions (as described above) to a greater extent when enhancing positive affective experiences in the laboratory. The stronger engagement of these emotion-related brain regions, especially given the involvement of the VS, may hint at a greater involvement of reward-related processes in these people during positive affetcive responding. Thus, people's subjective responses to rewards at the neural level may pose one of the processes underlying subjective well-being. Though this remains to be tested, this shows that a thorough understanding of the neural correlates of the affective processes may ultimately also advance our understanding of interindividual differences in subjective well-being.

10.3 Positive Affect Dynamics: Making the Most of the Least

None of the findings in the present dissertation were in favor of the proposition that the maximization of positive affective experiences (through enhanced affective reactivity or the up-regulation of positive emotions) relates to higher subjective well-being. One possible explanation for this may be that further increases in momentary affect are more difficult to accomplish for people with higher subjective well-being, due to their already high baseline levels of positive affect. Consistently, a previous study observed that savoring positive experiences had a greater impact on momentary happiness ratings for people who experienced positive events infrequently (Jose et al., 2012) – an indicator of relatively lower levels of subjective well-being (Diener, Sandvik, & Pavot, 2009). Or viewed from the opposite perspective, it might be simply easier to enhance one's current affect when one feels low, in line with the notion that positive emotions help to dampen negative affect and to recoer from negative and distressing experiences (Fredrickson & Levenson, 1998).

Findings from this dissertation also lend support for this idea that people benefit most from maximizing positive affective experiences in times of lower well-being. In *Paper I*, I observed unexpectedly strong increases in positive affect in the reactivity condition, due to a possible drop in baseline affect before this condition (likely due to the preceding sadness-inducing film clip). Hence, participants might have (implicitly or explicitly) maximized their positive affect to brighten their mood. In *Paper III,* enhanced affective reactions to positive events were observed in people with lower subjective well-being, possibly also reflecting a mood brightening effect (Grosse Rueschkamp et al., 2018). Moreover, this moderation effect of well-being on affective reactivity was most consistent across for negative affect as an outcome variable. This indicates that people with lower levels of well-being mostly experience a drop in negative affect when experiencing positive events. Finally, in *Paper II*, participants with lower overall daily affect (average affect during the experience-sampling period) more strongly engaged an emotion-related "core set" of brain regions (including the VS) when enhancing affect in the laboratory. As already discussed above, this may point to a potential stronger involvement of reward-related processes in these people. That is, people with lower daily affect may have lower expectations of positive experiences, which results in greater positive reward-prediction errors when something positive occurs (i.e., the actual positive experience exceeds one's expectations thereof) and subsequent increases in affect. Hence, it could be that when feeling comparatively low, one particularly profits from these (rather implicit) responses to rewards (i.e., positive experiences) in terms of their increases in momentary affect. In sum, these findings all underline the idea that maximizing positive affective experiences (through enhanced affective reactions or successful up-regulation) may help people "make the most of the least" when feeling low (Jose et al., 2012, p. 185).

10.4 Long-Term Dynamics of Positive Affective Experiences and Subjective Well-Being

The approach of this dissertation to investigate the affective processes underlying short-term changes in positive affective experiences to better understand interindividual differences in subjective well-being has partly been motivated by theoretical work on the long-term dynamics of daily affect and well-being. This work suggests that people's short-term responses to their changing affective

experiences accumulate and eventually impact the development of more enduring emotional outcomes, such as well-being (e.g., Hollenstein et al., 2013; Wichers, 2014). Accordingly, the recurrent heightened responses to daily positive experiences should lead to higher well-being.

Findings in this dissertation are only correlational and therefore no conclusions can be drawn regarding directions of effects. Still, the reduced affective reactions in people with lower subjective well-being do not seem to be in accordance with the just mentioned theoretical ideas. Instead, I would speculate the following: People's affective responses (e.g., affective reactions and up-regulation efforts) to positive experiences are of particular relevance when one feels low, such as in in times of increased stress or after experiencing a negative life event. In these times, people may experience particular strong increases in their positive affect when they experience something positive, given their comparably low baseline levels of affect (lower positive and higher negative affect; see also 10.3). Here, positive affective responses might reflect something like a "mood-brightening effect" (Bylsma et al., 2011, p. 155). Over time, the heightened positive affective experiences accumulate and eventually may elicit positive change in one's levels of well-being. Importantly, with increasing levels of subjective well-being, positive events and related affective short-term gains (e.g., increases in positive affect) seem to lose in importance.

These speculated long-term dynamics of positive affective experiences and subjective well-being would deviate from those of *negative* affect dynamics and *lower well-being*. Here, it has been shown (in accordance with the above outlined theories on the coupling of short- and long-term dynamics) that heightened responses to daily negative experiences predict increases in future depressive symptoms (Brose et al., 2017). Thus, those people with the lowest levels of well-being are characterized by the strongest responses to daily negative experiences. This pattern clearly does not mirror the pattern found in this dissertation: People with highest levels of well-being were not to characterized by the strongest, but by the weakest reactions to positive events (Grosse Rueschkamp et al., 2018). It therefore seems as if the processes underlying negative affect dynamics and lower well-being, as described by theoretical accounts and empirical findings, may not simply be transferrable to those underlying positive affective experiences and subjective well-being. This also becomes apparent in more short-term mechanisms, such as the differential psychological and neural processes underlying

the regulation of negative and positive emotions. While the former depends on the inhibition of an affective reaction, neurally supported by the recruitment of a fronto-parietal control network (Ochsner et al., 2012), the regulation of positive emotions rather works through the reinforcement of an affective experience and the suppression of this same fronto-parietal control network (*Paper II*). Together, the work in this dissertation points to fundamental differences in the basic mechanisms underlying short- and (as speculated) long-term dynamics of positive and negative affective experiences and global well-being outcomes.

Importantly, also leading theories from positive psychology, which aim to explain positive affective functioning and particular high levels of subjective well-being, do not seem to describe the above speculated long-term dynamics of positive affect dynamics and subjective well-being. The broaden-and-build theory, for example, posits that positive emotions trigger upwards spirals towards higher subjective well-being (Fredrickson, 2001). Thus, initial positive affective experiences increase the frequency and intensity of future positive experiences and eventually lead to increased subjective well-being. Based on this, one would expect people with higher subjective well-being to experience the strongest positive affect – contrasting the finding of a relation between reduced affective reactivity and higher well-being in this dissertation.

Even though the broaden-and-build theory does not seem fully capture the long-term dynamics of positive affect dynamics and subjective well-being, it, nevertheless, may provide an indication of some of the mechanisms through which positive affective experiences possibly elicit long-term change in times of lower well-being. For example, the broaden-and-build theory states that positive affect broadens people's attention and behaviors in ways that, over time, help build psychological and physical resources (Fredrickson, 2001). Thus, positive affective experiences may trigger specific feelings, behaviors or thoughts in people with lower levels of well-being, which motivate them to explore and to engage in activities that they may otherwise to pursue (e.g., social encounters or physical exercise). These new experiences may then positively impact their psychological and physical functioning and eventually also their subjective well-being.

10.5 Assessing Affective Reactivity, Emotion Regulation and Subjective Well-Being

Affective reactivity, emotion regulation and subjective well-being were assessed through different measures and methods in the present dissertation (for an overview of these measures and methods see Table 2). In the laboratory, affective reactivity and emotion regulation were assessed through self-reports of momentary affect when participants were instructed to react to or to up-regulate in response to standardized stimuli (e.g., positive images or film clips; *Papers I* and *II*). These measures at the subjective level were complemented through measures of BOLD-signal at the neural level (*Paper II*). Additionally, trait emotion regulation was assessed through self-reports of habitual or typical emotion regulation behaviors (*Paper I*). In daily life, affective reactivity was assessed through self-reports of momentary affect in response to self-reported daily events and emotion regulation through self-reports of affect and self-reported degree of up-regulating positive emotions (*Papers II*). Finally, subjective well-being was assessed either through self-reports (*Papers I* and *III*) or through self-reported momentary affective experiences in daily life that were then aggregated (*Papers II* and *III*). In the following, I will discuss how the different measures of affective reactivity and emotion regulation fit together and how they diverge. Additionally, I will discuss possible implications of using different methods in the study of affective processes and subjective well-being.

Subjective and neural level. Measures of affective reactivity and emotion regulation at the subjective and the neural level showed both associations, as well as dissociable effects. At the subjective level, participants experienced increases in momentary affect when they reacted to positive stimuli in the laboratory and participants were able to further increase their momentary affect when instructed to up-regulate (*Paper II*). Overall, these findings were mirrored at the neural level: Increases in momentary affect (through either affective reactions or through the engagement in up-regulation efforts) selectively engaged a network of emotion-related brain regions. Increased VS activity in particular, known to be specifically involved in reward-related processes (e.g., Kringelbach & Berridge, 2009), was identified as a neural indicator for the successful up-regulation of positive emotions.

However, there were also instances in which there was no clear mapping between reports of affective experiences and neural activations. First, VS activity did not relate to changes in affect when

up-regulating positive emotions in daily life, which is most likely due to the different methods used (i.e., task-based fMRI in the laboratory versus experience-sampling in daily life, see below). Second, the up-regulation in response to neutral stimuli was related to increased activation in the VS, which was not paralleled by changes in the subjective experience of affect. Given our experimental manipulation (i.e., instruction to up-regulate in response to neutral images), this finding points towards a different psychological function of the VS during the regulation process, such as the representation of a regulation goal (Ochsner et al., 2012).

The inclusion of measures of affective reactivity and emotion regulation at the neural level, in addition to observations at the subjective level, has helped identify the brain regions that underlie the affective processes. However, the present findings at the neural level also led to insights that would not be obtainable by relying on the level of subjective experience alone: Increases in positive affective experiences were not only associated with activation in emotion-related brain regions but also with deactivation of the fronto-parietal network, likely suggesting relative less recruitment of cognitive control functions when enhancing positive affective experiences. In sum, the present findings show that the investigation of affective reactivity and emotion regulation through both subjective and physiological data can substantially advance our understanding of the affective processes.

Table 2

Overview of Measures and Methods Used to Assess Affective Reactivity, Emotion Regulation, and Subjective Well-Being in the Present Dissertation

		Laboratory			**Daily life**
		Subjective experience		Neural level	Subjective experience
		Emotion regulation paradigm	*Self-reports*	*fMRI*	*ESM / Daily Diary*
Affective reactivity	Paper I	Change in PA when instructed to react to positive film clip			
	Paper II	Change in overall affect when instructed to react to positive images		BOLD signal when reacting to positive images	
	Paper III				Within-person association between PA/NA/overall affect and positive events
Emotion regulation	Paper I	Change in PA when instructed to up-regulate versus reacting to positive film clip	Habitual emotion regulation [CERQ, ERQ, ERP-R]		
	Paper II	Change in overall affect when instructed to up-regulate versus reacting to positive images		BOLD signal when instructed to up-regulate (versus reacting) to positive images	Change in overall affect as predicted by degree of up-regulating positive emotions
Subjective well-being	Paper I		Cognitive and affective component [SWL, PANAS positive, WHO]		
	Paper II			Aggregated overall affect	
	Paper III		Cognitive and affective component, depressive symptoms [SWL, PANAS, CES-D]	Aggregated PA/ NA	

Notes. fMRI = functional Magnetic Resonance Imaging; ESM = experience sampling method; PA = positive affect; NA = negative affect; CERQ = Cognitive Emotion Regulation Questionnaire; ERP-R = Emotion Regulation Profile Revised; ERQ = Emotion Regulation Questionnaire; SWL = Satisfaction with Life Scale; PANAS = Positive and Negative Affect Schedule; WHO-5 = WHO (Five) Well-being Index; CES-D = Center for Epidemiologic Studies Depression Scale

Changes in affective experiences versus retrospective self-report. All studies that contributed to this dissertation assessed affective reactivity and emotion regulation through self-reports of momentary affective states (i.e., performance-based indicators), either in an emotion regulation paradigm in the laboratory (*Papers I* and *II*) or through the experience-sampling and daily diary method (*Papers II* and *III*). In *Paper 1*, positive emotion regulation was additionally assessed through retrospective self-reports, which reflect trait-level differences in regulatory behaviors, such as frequent or typical emotion regulation behaviors. Though these trait levels of emotion regulation are also thought to be indicative of one's emotion regulation capacities, there was no significant association between performance-based indicators of emotion regulation and trait levels of emotion regulation (*Paper I*). Additionally, only trait emotion regulation was significantly (positively) related to self-reported subjective well-being (*Paper I*).

The discrepancy between trait level indicators and performance-based indicators of affective reactivity and emotion regulation can potentially be explained by a discrepancy in the sources of memory retrospective self-reports and reports of momentary affective experiences draw on. More precisely, according to Robinson and Clore (2002a, 2002b), online reports of emotion (i.e., assessments of momentary affect) make use of an actual subjective experience in a certain moment. Retrospective self-reports (i.e., self-reports of emotion regulation), instead, draw on semantic knowledge that include various biases, such as identity-related beliefs or cultural beliefs about emotion. Therefore, measures of changes in affect, captured through the repeated assessment of momentary affective states, should be more accurate indicators of affective reactivity or emotion regulation. Similarly, aggregated means of momentary affective states that are captured repeatedly over time (*Papers II* and *III*), should be more accurate indicators of average levels of affective experiences (i.e., the affective component of subjective well-being), as compared to those captured through self-reports of subjective well-being (e.g., Positive and Negative Affect Schedule; Watson, Clark, & Tellegen, 1988).

The described differences in reports may also explain why only trait reports of emotion regulation were significantly linked to self-reported subjective well-being (*Paper I*). Subjective well-being, just as trait emotion regulation, was assessed via retrospective self-reports, likely including the

same biases. Thus, it could be speculated that individuals with higher subjective well-being might hold beliefs about themselves and their emotional competencies, due to personality characteristics for example, that makes them more likely to rate both their subjective well-being and their emotion regulation capacities as higher. Such integration of beliefs does not occur, however, in online reports of momentary experiences.

More generally, these differences between measures (i.e., retrospective self-reports versus changes in affective experiences) also potentially explain why most findings in this dissertation diverge from earlier research from the realm of positive psychology. The latter reported a positive relation between the affective processes and subjective well-being (e.g., Bryant, 2003; Carl et al., 2014). The majority of these previous studies relied on retrospective self-reports of affective reactivity or positive emotion regulation, while studies in this dissertation captured these affective processes as they occur within individuals. Subjective well-being was not significantly associated with within-person changes in positive affect in the laboratory (*Paper I*) and negatively associated with within-person associations between positive affect and positive events in daily life (Grosse Rueschkamp et al., 2018). Together, the findings in this dissertation emphasize the need for repeated assessments of affect within individuals to better understand affective reactivity and emotion regulation and their relation to interindividual differences in subjective well-being.

Laboratory and daily life. A methodological strength of the dissertation was the inclusion of different measures from both the laboratory and daily life. Each of these methods had its advantage, providing valuable insights into affective reactivity and emotion regulation. High experimental control and careful experimental manipulations in the laboratory (*Papers I* and *II*) allowed getting a better mechanistic understanding of the affective processes. For example, successful up-regulation of positive emotions was assessed as the change in affect when participants were instructed to up-regulate versus when they simply reacted to positive stimuli, thus, disentangling regulatory effects from initial affective reactions. Similarly, through the use of standardized stimuli (i.e., images and film clips), it was possible to control for the type, valence, and intensity of the emotion induction. In *Paper II*, for instance, I found that the VS is not only activated during the up-regulation of positive emotions

but also when up-regulating in response to neutral images, suggesting also an affect-independent function of the VS in the regulatory process.

The use of experience-sampling or daily-diary methods in daily life allowed to capture affective reactivity and emotion regulation as they unfold in the context of everyday life, maximizing ecological validity (Hoppmann & Riediger, 2009). For example, it was possible to observe momentary affective experiences and idiographic events over a longer period of time (up to 10 days for the experience-sampling studies and up to 101 days for the daily diary study in Grosse Rueschkamp et al., 2018).

Some findings in this dissertation suggest a link across these different methods. In *Paper II,* I found average levels of affect in the laboratory (across all trials) to be positively related to average levels of affect in daily life (across all measurement occasions). Additionally, lower average daily affect was related to increased engagement of an emotion-related set of brain regions when enhancing affective experiences in the laboratory (*Paper II*). However, there were also discrepancies in findings across methods. For example, there was no relation between affective reactivity or the up-regulation of positive emotions and subjective well-being in the laboratory (*Paper I*). Yet, higher subjective well-being was significantly related to reduced affective reactivity to positive events in daily life (Grosse Rueschkamp et al., 2018). Moreover, no significant association was found between VS activity during the up-regulation in the laboratory and changes in affect when up-regulating in daily life, as assessed *within* the same sample. Some of the above described methodological differences possibly explain these inconsistencies in findings.

First, instructed (as measured in the laboratory paradigms) and spontaneous emotion regulation (as measured in daily life) may reflect different regulation capacities. For example, spontaneous regulation might encompass the capacity to determine whether regulation is required, while instructed regulation might rather indicate the ability to follow instructions. Second, the use of standardized stimuli in the laboratory versus idiographic events in daily life may have differently impacted the observed effects. For example, the greater personal relevance of idiographic events in daily life may have motivated people to attend to them more and to regulate their emotions to a greater extent. Possibly, such enhanced motivation was particularly pronounced in people with lower

subjective well-being, who do not experience positive events frequently (Oishi et al., 2007). Thus, this may offer an explanation for why there was a significant (negative) association between reactivity and subjective well-being in daily life (*Paper II*), but not in the laboratory (*Paper I*).

Additionally, changes in affect are assessed at different timescales in the laboratory and in daily life, possibly capturing different affective processes (Hollenstein et al., 2013; Koval, Pe, Meers, & Kuppens, 2013). For instance, compared to emotions, moods are often thought to be longer-lasting and slower (Rosenberg, 1998). Therefore, changes in affect that are assessed over seconds or minutes in the laboratory likely reflect emotion-related processes, whereas affective changes that are captured over hours or days (as in daily life) may be driven by mood-related processes (Rottenberg, 2005).

Taken together, the integration of methods from the laboratory and daily life has led to some important insights into the affective processes affective reactivity and emotion regulation. The established associations between affect in the laboratory and daily affect, as well as task-based neural activations and daily affect provide evidence of a link between laboratory and daily life. Yet, a greater parallelism between specific measures could help to detect more fine-grained processes (e.g., regulation processes) across both laboratory and daily life.

General methodological considerations. The present dissertation presents a broad empirical approach to the study of affective reactivity, emotion regulation and subjective well-being. This approach integrated measures at two levels of analysis (i.e., subjective and neural level), performance-based measures from both the laboratory and daily life and self-reports of the affective processes. While the use of these various measures and methods has led to some valuable insights on affective reactivity, emotion regulation and their relation to subjective well-being, it has also become apparent that findings across these different measures and methods do not necessarily align. This realization leads to several important implications for the study of the affective processes and subjective well-being. First, it is crucial to determine which measure and method is best suited for capturing the phenomenon under investigation. For example, if the focus of investigation lies on phenomena that show substantial within-person variability (e.g., affective experiences), it is essential to capture them repeatedly within individuals across time. One-time assessments do not suffice to describe these phenomena accurately and may lead to premature conclusions. Second, it is important to consider if

and to what extent findings obtained across different methods are comparable. It is common among researchers to assume, for example, that laboratory results predict behavior in the daily life, yet, without explicitly testing such link between laboratory and daily life, this assumption may not be justified. In sum, the findings in this dissertation stress the need to integrate different methods in the study of the emotion to apprehend a more comprehensive picture of the processes underlying subjective well-being.

11 Limitations

Affective reactivity and emotion regulation. Affective reactivity and emotion regulation were conceptualized as distinct affective processes throughout this dissertation. Besides empirical efforts to measure these separately, a clear-cut distinction might be questionable. For example, during experience-sampling in daily life, ratings of momentary affect do not immediately follow upon the occurrence of a positive event (but up to two hours later). Therefore, instead of reflecting enhanced affective reactions, heightened momentary affect may also reflect regulatory efforts, in terms of efforts to prolong one's positive affective experiences (one constituent element of the concept of savoring; Bryant & Veroff, 2007). This blurring of affective reactivity and emotion regulation is usually of less concern in laboratory research paradigms, where participants are instructed to either simply react to or to regulate. Nevertheless, a distinction between affective reactivity and emotion regulation can also be ambiguous in the laboratory, due to other features of experimental design choices (e.g., negative-valenced stimuli). For example, the intermixed negative-valenced stimuli in the emotion regulation task in *Paper I* have likely led to different baselines of affect in the experimental conditions, which in turn may have impacted the degree of affective reactivity and emotion regulation (see also 10.3). However, given that affective reactivity and emotion regulation are strongly related and intertwined, even when measured perfectly, it is difficult to say with certainty to what extent they might have influenced each other.

Emotion regulation strategies. We did not instruct the use of specific up-regulation strategies in our laboratory paradigms (*Papers I* and *II*), therefore, no conclusions can be drawn regarding the effectiveness of specific regulation strategies or the number of different strategies used. It further

makes the present findings less comparable to previous studies, most of which focused on the investigation of specific strategies (Buhle et al., 2014; Webb et al., 2012). Still, our rationale behind our paradigm was that we wanted to maximize comparability to empirical investigations of emotion regulation in daily life, where people often report using several (up to eight in Heiy & Cheavens, 2014) different strategies in an attempt to up-regulate positive emotions. For this reason we opted for an emotion regulation paradigm in which participants were not instructed to use a specific regulation strategy.

Affect measures. Momentary affect was measured differently across the different studies in this dissertation (for an overview, see Table 2), posing a constraint on the comparability of reactivity and regulation: In *Paper I* only positive affect was assessed, in *Paper II* overall affect was assessed through a bipolar affect item (indicative of overall momentaryaffect), and the studies contributing to *Paper III* captured positive and negative affect separately or overall momentary affect (Grosse Rueschkamp et al., 2018). Specifically through the use of a bipolar affect item in *Paper II*, it is not possible to distinguish the effects of reactivity and regulation on either valence (i.e., increases in positive versus decreases in negative affect), as it has been observed by Grosse Rueschkamp and colleagues (2018). However, given the particular time constraints during fMRI and participants' burden of completing a total of 160 ratings of their momentary affect (pre- and post-stimulus rating on 80 trials), a more differentiated affect measure comprising positive and negative valence items would not have been feasible.

Multimethod approach. Not all hypotheses have been tested both in the laboratory and in daily life. For instance, the hypothesized relation between greater up-regulation success of positive emotions and higher subjective well-being was only tested in the laboratory, leaving it an open question whether such relation would be detected when investigated in daily life. This possibility seems particularly appealing since a significant relation between affective reactivity and subjective well-being was evident in daily life (Grosse Rueschkamp et al., 2018) but not in the laboratory (*Paper I*). It seems possible, for example, that people are more engaged in up-regulation efforts when they actually experience positive events in their own lives, as opposed to when positive affect is induced through standardized images in the laboratory, without any personal relevance.

A specific limitation concerns the examination of brain-daily life associations in *Paper II*, which reflects a rather novel empirical approach. Given the small empirical basis (only few studies used a similar approach, but see for example Heller et al., 2015; Seidel et al., 2018) the specific tested associations have to be considered exploratory. As exploratory analyses are always more open to biases (e.g., regarding selection of variables) and more prone to false positives (Simmons, Nelson, & Simonsohn, 2011), the respective findings (i.e., relation between lower overall daily affect and greater engagement of emotion-related brain regions when enhancing positive affective experiences) require to be replicated through confirmatory research.

Sample characteristics. All samples that were used across the different studies in this dissertation consisted of young adults aged between 17 and 31 years (with the sample in *Paper II* only ranging from 20 to 25 years). While this rather narrow sampling was deemed necessary to keep the influence of confounding factors to a minimum, it limits the generalizability of the findings. Central variables in this dissertation have previously been related to age-group differences, such affective reactivity to positive events, which has been shown to be reduced in older, compared to younger participants (Röcke, Li, & Smith, 2009). Thus, it seems possible that reported associations in this dissertation (e.g., the link between affective reactivity and subjective well-being) are subject to change through the emotional development across the life-span. The present findings should therefore be tested in samples comprising different age groups.

12 Future Research Directions

The findings in this dissertation bear several implications and directions for future research. These implications concern the assessment of affective reactivity and emotion regulation across multiple methods (across the laboratory and daily life in particular), specific challenges of studying positive affective experiences, a possible link between neural processes and interindividual differences in subjective well-being, possible long-term dynamics of positive affective experiences, and potential implications of positive affect dynamics in clinical settings.

Determining indicators for affective reactivity and emotion regulation. One important avenue for future research would be to do a comprehensive assessment of affective reactivity and emotion

regulation across different methods and to systematically test how and to what extent they converge and possibly diverge. Similarly to the approach taken in this dissertation, these indicators should encompass measures at multiple levels of analysis, such as the behavioral, subjective, and the (neuro-) physiological level, and should be assessed both in the laboratory and in daily life. While some measures, such as those of brain functioning, are only limitedly assessable in daily life (but see Mihajlovic, Grundlehner, Vullers, & Penders, 2015 for applications of electroencephalography in daily life activities), various other behavioral, experiential and physiological (e.g., cardiovascular or respiratory) measures have been obtained through ambulatory assessments and successfully linked to affective experiences (Wilhelm, Pfaltz, & Grossman, 2006). Importantly, to disentangle possible discrepancies across different methods, it would be of particular value to do such systematic test of affective reactivity and emotion regulation *within* the same sample, similar to the approach taken in this dissertation (*Paper II*). Moving forward, a comprehensive investigation of affective reactivity and emotion regulation across multiple levels of analysis and methods would pose an important step in understanding the processes underlying subjective well-being.

Testing generalizability of research findings from laboratory in daily life. Directly related to the above, one major challenge for future research is to test how findings from the laboratory translate to behavior and functioning in daily life. One important step in this direction is to establish a parallelism between laboratory and daily life measures. First, laboratory research designs might be modified such that they mirror real-world conditions more accurately. For example, idiographic stimuli (e.g., autobiographical memories) could be used instead of standardized images, as these possess higher self-relevance (Salas, Radovic, & Turnbull, 2012). New technologcial advances, like virtual reality, may also help to better account for the complexity of real-life situations and interactions in the laboratory, providing higher realism in controlled experimental conditions (Biedermann et al., 2017). For example, elements in virtual reality unfold more dynamically (than, e.g., a static 2D photograph) and last longer (than one trial length) than conventional stimuli (e.g., images).

Given the limited room for compromises in controlled experiments in the laboratory, especially in highly constrained fMRI settings, it is also essential to consider adjustments of research paradigms in daily life. One such adjustment would be to experimentally manipulate events in daily

life. This would ensure that all participants experience the same event but at the same time maximize ecological validity through the measurement of affective processes in daily life. Such an approach has previously been applied in a study investigating the effects of social stress on emotional inertia. The authors successfully induced social stress in daily life by informing their participants of the requirement to perform the Trier Social Stress Test and simultaneously measured affect with the experience-sampling method (Koval & Kuppens, 2012). Taken together, work has to be done to further address and test the ecological validity of research findings from the laboratory to be able to draw firm conclusions about how these findings explain behavior in the context of everyday life.

Reward responsiveness, affective reactivity and subjective well-being. One major finding from the work in this dissertation is that people with higher levels of subejctive well-being seem to be characterized by reduced affective reactivity to positive events in daily life (Grosse Rueschkamp et al., 2018). At the neural level, it has been shown that experiences of momentary happiness are best explaine by one's subjective responses to rewards. More specifically, in one fMRI study, participants completed a probabilistic reward task that involved decisions between risky and certain monetary choices (Rutledge et al., 2014). Results showed that, instead of task earnings being the main predictor of momentary happiness, subjective happines ratings were best explained by reward expectations and most strongly the resulting reward prediction errors (i.e., the difference between expected and actual outcome). Subjective ratings of happiness were additionally shown to correlate with VS activity (Rutledge et al., 2014). Given the in this dissertation reported relation between daily affective reactivity to positive events and subjective well-being, it would therefore be intriguing to test whether differences in one's subjective responses to rewards at the neural level possibly underlie these differences in affetcive reactions and overall levels of subjective well-being. It could be hypothesized, for example, that people with lower subjective well-being have lower expectations of positive experiences in their lives and thus have greater reward-prediction errors when something positive occurrs, leading to a stronger increase in their momentary affect. This hypothesis would also fit with the finding that people with lower daily affect to enagage emotion-related brain regions to a greater extent when increasing momentary affect (*Paper II*), as this greater engagement may speak for increased reward-related processing in people with lower subejctive well-being. Yet, a direct test of a

relation between differences in reward-responsiveness, affective reactivity to positive events and overall levels of subjective well-being is still needed.

Current work from our research group might be able to shed light on this. As part of the same research project that was reported in *Paper II*, participants additionally enaged in a reward-learning task, in which they had to play slot machines with varying probabilities of dispensing monetary rewards (see also Eldar & Niv, 2015). Given the systematic manipulation of the likelihood of obtaining these rewards it is possible to test how momentary positive affective experiences may be shaped by expectations about rewarding outcomes and resulting reward-prediction errors. These neural processes can subsequently be linked to daily affect dyamics (e.g., affective reactions to daily positive events) as captured through the experience-sampling method (see *Paper II* for details) and, ultimately, also overall levels of subjective well-being.

Challenges of studying positive affective experiences. The study of positive affective experiences comes with particular challenges that researchers have to deal with. First, positive experiences, as compared to negative, tend to elicit less strong short-term reactions in terms of behavioral, cognitive and affective responses (Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001), as well as neural responses (Ito, Larsen, Smith, & Cacioppo, 1998). This poses researchers with the challenge of designing experiments that elicit clear and reliable affective reactions when, for example, aiming to induce positive emotions in the laboratory.

Fittingly, positive emotions usually yield smaller effect sizes than negative ones (Cohn & Fredrickson, 2009). As compared to negative affect dynamics, the association between positive affect dynamics and well-being has been reported to be smaller in a meta-analysis (Houben et al., 2015). Similarly, the impact on long-term change in personality traits, has been proposed to be smaller for daily positive than daily negative experiences (Mund & Neyer, 2014; Wrzus & Roberts, 2017). In the present dissertation, I tried to tackle this challenge through the use of relatively large samples, ranging from $N = 70$ to 200 for the behavioral studies (*Papers I* and *III)* and $N = 63$ for the fMRI study (*Paper II)*, aiming to achieve sufficient power to detect possible effects. Nevertheless, the comparatively small effect sizes remain an important consideration when studying positive affective experiences and should be taken into account by researchers.

Long-term dynamics of positive affective experiences and subjective well-being. Based on the picture that emerged in the present dissertation, I already speculated on the possible prospective effects of positive affect dynamics on the development of subjective well-being. One important avenue for future research would be to identify such developmental pathways. Emerging research on the long-term couplings of negative affect dynamics and global individual differences variables (e.g., symptoms of psychopathology; Brose et al., 2017), as well as first advances in linking positive affect dynamics to long-term personality change (Borghuis et al., 2018), can serve as starting points. These studies utilized so-called "measurement-burst designs", which encompass a combination of micro-longitudinal (e.g., experience-sampling or daily diary methods) and longitudinal designs and are therefore well-suited for investigating long-term change within individuals (Nesselroade, 1991; Sliwinski, 2008).

A recent study on positive affect dynamics and personality change applied such approach. In this study middle-aged women completed three measurement bursts per year over a five-year period, in which positive experiences were assessed daily. Results indicated that daily positive experiences were related to rank-order increases in extraversion, agreeableness, conscientiousness, emotional stability and openness (Borghuis et al., 2018). Though the long-term dynamics of positive affect dynamics and subjective well-being have yet to be identified, this study lends first support for the idea that daily positive affect dynamics can elicit long-term change. Importantly, the reported finding that daily positive affect leads to long-term changes in personality traits (Borghuis et al., 2018) may be in accordance with the idea that positive affect dynamics may have the strongest impact on long-term change in times of lower well-being (as elaborated on above). Given that the reported trait changes concerned rank-order changes, it would possible, for example, that those participants, who initially experienced the lowest levels of daily positive affect, benefited the most from their positive affective experiences and therefore showed the strongest trait changes. However, this interpretation of the results from Borghuis and colleagues (2018) has yet to be tested. Insights into developmental pathways of subjective well-being may not only inform on the processes fostering higher levels of subjective well-being, but may also be of practical relevance for interventions in clinical settings, as I will elaborate on next.

Positive affect dynamics in clinical settings. Following up on potential developmental pathways of subjective well-being, the question arises to what extent positive affect dynamics might be a promising avenue for clinical research, and potential clinical interventions in particular. In line with the finding that people with lower levels of well-being profit more from positive events in terms of their momentary affect (Grosse Rueschkamp et al., 2018), it seems possible, for example, that positive affective experiences may be used to foster positive change in people who undergo a depressive episode or are otherwise affected by a mental disorder. Similarly, other findings from the work in this dissertation might reveal a particular path, where the cultivation of behaviors to maximize positive affective experiences seems particularly fruitful. As the enhancement of momentary affect was associated with relative less neural activation in a fronto-parietal network, previously implicated in cognitive control processes (*Paper II*), cultivating positive affect dynamics might be particularly valuable for people who have difficulties with implementing otherwise cognitive-laden strategies (e.g., strategies aimed at down-regulating negative affect). These examples illustrate how positive affect dynamics, informed by findings from work in the present dissertation, may constitute a component of clinical interventions (Carl, Soskin, Kerns, & Barlow, 2013; Garland et al., 2010). But undoubtedly, a possible relevance of these positive dynamics in the clinical context has yet to be established and should be a goal for future research.

13 Conclusion

Positive events are an integral part of everyday life. Our reactions to these shape our positive affective experiences and through the deliberate up-regulation of these experiences we can even further improve the way we feel. In this dissertation I investigated the idea that the maximization of positive affective experiences is one of the mechanisms underlying higher subjective well-being.

Empirically, the picture that emerged in this dissertation does not speak for a central role of intense positive affective experiences – through enhanced affective reactivity to positive events or greater increases in positive affect when up-regulating positive emotions – in higher subjective well-being. Rather, higher levels of subjective well-being seem to be reflected in dynamic aspects of positive affective experiences, such as a relative greater emotional stability, as indicated through less

fluctuation in positive affect when experiencing positive events in daily life. Yet, enhancing everyday positive experiences can be a meaningful way to brighten one's current mood, especially in times of lower well-being. The picture that emerged in this dissertation was supported through findings obtained at the subjective and the neural level, as well as in the laboratory and in daily life.

Overall, the present findings underscore the importance of taking dynamic aspects into account to better understand how daily positive affective experiences contribute to higher levels of subjective well-being. Given the rather inconsistent pattern of findings across methods, the work in this dissertation also points to the need of integrating different methods in the study of affect dynamics when aiming to delineate the processes underlying subjective well-being. Together, it became apparent that more theoretical and empirical work is needed to obtain a comprehensive understanding of the role of positive affective processes in subjective well-being and how individual differences in subjective well-being come about. Though it seems, as if the quest for happiness is not as straightforward as one may think.

14 References

Affleck, G., Tennen, H., Urrows, S., & Higgins, P. (1994). Person and contextual features of daily stress reactivity: Individual differences in relations of undesirable daily events with mood disturbance and chronic pain intensity. *Journal of Personality and Social Psychology*, *66*(2), 329–340. http://doi.org/10.1037//0022-3514.66.2.329

Aldao, A., Nolen-Hoeksema, S., & Schweizer, S. (2010). Emotion-regulation strategies across psychopathology: A meta-analytic review. *Clinical Psychology Review*, *30*(2), 217–237. http://doi.org/10.1016/j.cpr.2009.11.004

Apicella, P., Ljungberg, T., Scarnati, E., & Schultz, W. (1991). Responses to reward in monkey dorsal and ventral striatum. *Experimental Brain Research*, *85*(3), 491–500. http://doi.org/10.1007/BF00231732

Araújo, D., Davids, K., & Passos, P. (2007). Ecological validity, representative design, and correspondence between experimental task constraints and behavioral setting: Comment on Rogers, Kadar, and Costall (2005). *Ecological Psychology*, *19*(1), 69–78. http://doi.org/10.1080/10407410709336951

Ashby, F. G., & Isen, A. M. (1999). A Neuropsychological theory of positive affect and its influence on cognition. *Psychological Review*, *106*(3), 529–550. http://doi.org/10.1007/BF00896764

Augustine, A. A., & Hemenover, S. H. (2009). On the relative effectiveness of affect regulation strategies: A meta-analysis. *Cognition and Emotion*, *23*(6), 1181–1220. http://doi.org/10.1080/02699930802396556

Barrett, L. F. (2009). The future of psychology: Connecting mind to brain. *Perspectives on Psychological Science*, *4*(4), 326–339.

Baumeister, R. F., Bratslavsky, E., Finkenauer, C., & Vohs, K. D. (2001). Bad is stronger than good. *Review of General Psychology*, *5*(4), 323–370. http://doi.org/10.1037/1089-2680.5.4.323

Berns, G. S., Mcclure, S. M., Pagnoni, G., & Montague, P. R. (2001). Predictability modulates human brain response to reward. *The Journal of Neuroscience*, *21*(8), 2793–2798.

Berridge, K. C. (2019). Affective valence in the brain: modules or modes? *Nature Reviews Neuroscience*. http://doi.org/10.1038/s41583-019-0122-8

Berridge, K. C., & Kringelbach, M. L. (2008). Affective neuroscience of pleasure: Reward in humans and animals. *Psychopharmacology*, *199*(3), 457–480. http://doi.org/10.1007/s00213-008-1099-6

Berridge, K. C., & Kringelbach, M. L. (2013). Neuroscience of affect: Brain mechanisms of pleasure and displeasure. *Current Opinion in Neurobiology*, *23*(3), 294–303. http://doi.org/10.1016/j.conb.2013.01.017

Biedermann, S. V., Biedermann, D. G., Wenzlaff, F., Kurjak, T., Nouri, S., Auer, M. K., … Fuss, J. (2017). An elevated plus-maze in mixed reality for studying human anxiety-related behavior. *BMC Biology*, *15*(1), 125. http://doi.org/10.1186/s12915-017-0463-6

Blanke, E. S., & Brose, A. (2017). Mindfulness in daily life: A multidimensional approach.

Mindfulness, *8*(3), 737–750. http://doi.org/10.1007/s12671-016-0651-4

Blanke, E. S., Brose, A., Kalokerinos, E. K., Erbas, Y., Riediger, M., & Kuppens, P. (2019). Mix it to fix it: Emotion regulation variability in daily life. *Emotion*. http://doi.org/10.1037/emo0000566

Blood, A. J., & Zatorre, R. J. (2001). Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion. *Proceedings of the National Academy of Sciences*, *98*(20), 11818–11823. http://doi.org/10.1073

Boehm, J. K., & Kubzansky, L. D. (2012). The heart's content: The association between positive psychological well-being and cardiovascular health. *Psychological Bulletin*, *138*(4), 655–691. http://doi.org/10.1037/a0027448

Bonanno, G. A., & Burton, C. L. (2013). Regulatory flexibility. *Perspectives on Psychological Science*, *8*(6), 591–612. http://doi.org/10.1177/1745691613504116

Borghuis, J., Denissen, J. J. A., Sijtsma, K., Branje, S., Meeus, W. H. J., & Bleidorn, W. (2018). Positive daily experiences are associated with personality trait changes in middle-aged mothers. *European Journal of Personality*, *32*(6), 672–689. http://doi.org/10.1002/per.2178

Bradburn, N. M. (1969). *The structure of psychological well-being.* Chicgaco: Aldine.

Brans, K., Koval, P., Verduyn, P., Lim, Y. L., & Kuppens, P. (2013). The regulation of negative and positive affect in daily life. *Emotion*, *13*(5), 926–939. http://doi.org/10.1037/a0032400

Brose, A., Schmiedek, F., Lövdén, M., & Lindenberger, U. (2011). Normal aging dampens the link between intrusive thoughts and negative affect in reaction to daily stressors. *Psychology and Aging*, *26*(2), 488–502. http://doi.org/10.1037/a0022287

Brose, A., Voelkle, M. C., Lövdén, M., Lindenberger, U., & Schmiedek, F. (2015). Differences in the between-person and within-person structures of affect are a matter of degree. *European Journal of Personality*, *29*(1), 55–71. http://doi.org/10.1002/per.1961

Brose, A., Wichers, M., & Kuppens, P. (2017). Daily stressful experiences precede but do not succeed depressive symptoms: Results from a longitudinal experience sampling study. *Journal of Social and Clinical Psychology*, *36*(3), 196–220. http://doi.org/10.1521/jscp.2017.36.3.196

Bryant, F. B. (2003). Savoring Beliefs Inventory (SBI): A scale for measuring beliefs about savouring. *Journal of Mental Health*, *12*(2), 175–196. http://doi.org/10.1080/0963823031000103489

Bryant, F. B., & Veroff, J. (2007). *Savoring: A new model of positive experience.* Mahwah, NJ: Lawrence Erlbaum.

Buckholtz, J. W., Treadway, M. T., Cowan, R. L., Woodward, N. D., Benning, S. D., Li, R., … Zald, D. H. (2010). Mesolimbic dopamine reward system hypersensitivity in individuals with psychopathic traits. *Nature Neuroscience*, *13*(4), 419–421. http://doi.org/10.1038/nn.2510

Buhle, J. T., Silvers, J. A., Wager, T. D., Lopez, R., Onyemekwu, C., Kober, H., … Ochsner, K. N. (2014). Cognitive reappraisal of emotion: A meta-analysis of human neuroimaging studies. *Cerebral Cortex*, *24*(11), 2981–2990. http://doi.org/10.1093/cercor/bht154

Bylsma, L. M., Morris, B. H., & Rottenberg, J. (2008). A meta-analysis of emotional reactivity in

major depressive disorder. *Clinical Psychology Review*, *28*(4), 676–691. http://doi.org/10.1016/j.cpr.2007.10.001

Bylsma, L. M., Taylor-Clift, A., & Rottenberg, J. (2011). Emotional reactivity to daily events in major and minor depression. *Journal of Abnormal Psychology*, *120*(1), 155–167. http://doi.org/10.1037/a0021662

Cacioppo, J. T., & Berntson, G. G. (1999). The affect system. *Current Directions in Psychological Science*, *8*(5), 133–137. http://doi.org/10.1111/1467-8721.00031

Cacioppo, J. T., Gardner, W. L., & Berntson, G. G. (1997). Beyond bipolar conceptualizations and measures: The case of attitudes and evaluative space. *Personality and Social Psychology Review*, *1*(1), 3–25. http://doi.org/10.1207/s15327957pspr0101_2

Carl, J. R., Fairholme, C. P., Gallagher, M. W., Thompson-Hollands, J., & Barlow, D. H. (2014). The effects of anxiety and depressive symptoms on daily positive emotion regulation. *Journal of Psychopathology and Behavioral Assessment*, *36*(2), 224–236. http://doi.org/10.1007/s10862-013-9387-9

Carl, J. R., Soskin, D. P., Kerns, C., & Barlow, D. H. (2013). Positive emotion regulation in emotional disorders: A theoretical review. *Clinical Psychology Review*, *33*(3), 343–360. http://doi.org/10.1016/j.cpr.2013.01.003

Carstensen, L. L., Pasupathi, M., Mayr, U., & Nesselroade, J. R. (2000). Emotional experience in everyday life across the adult life span. *Journal of Personality and Social Psychology*, *79*(4), 644–655. http://doi.org/10.1037//0022-3514.79.4.644

Chaiken, S., & Trope, Y. (1999). *Dual-process theories in social psychology*. New York: Guilford Press.

Charles, S. T., Piazza, J. R., Mogle, J., Sliwinski, M. J., & Almeida, D. M. (2013). The wear and tear of daily stressors on mental health. *Psychological Science*, *24*(5), 733–741. http://doi.org/10.1177/0956797612462222

Cohn, M. A., & Fredrickson, B. L. (2009). Positive emotions. In C. R. Snyder & S. J. Lopez (Eds.), *Oxford handbook of positive psychology* (2nd ed., Vol. 2, pp. 13–24). New York: Oxford University Press.

Costa, P. T., & McCrae, R. R. (1980). Influence of extraversion and neuroticism on subjective well-being: Happy and unhappy people. *Journal of Personality and Social Psychology*, *38*(4), 668–678. http://doi.org/10.1037/0022-3514.38.4.668

Côté, S., Gyurak, A., & Levenson, R. W. (2010). The ability to regulate emotion is associated with greater well-being, income, and socioeconomic status. *Emotion*, *10*(6), 923–933. http://doi.org/10.1037/a0021156

Csikszentmihalyi, M., & Larson, R. (1987). Validity and reliability of the experience-sampling method. *Journal of Nervous and Mental Disease*, *175*(9), 526–536. http://doi.org/10.1007/978-94-017-9088-8

Danner, D. D., Snowdon, D. A., & Friesen, W. V. (2001). Positive emotions in early life and longevity: Findings from the nun study. *Journal of Personality and Social Psychology*, *80*(5), 804–813. http://doi.org/10.1037/0022-3514.80.5.804

Davidson, R. J. (1998). Affective style and affective disorders: Perspectives from affective neuroscience. *Cognition and Emotion*, *12*(3), 307–330. http://doi.org/10.1080/026999398379628

Delgado, M. R. (2007). Reward-related responses in the human striatum. *Annals of the New York Academy of Sciences*, *1104*(1), 70–88. http://doi.org/10.1196/annals.1390.002

Delgado, M. R., Locke, H. M., Stenger, V. A., & Fiez, J. A. (2003). Dorsal striatum responses to reward and punishment : Effects of valence and magnitude manipulations. *Cognitive, Aaffective & Behavioral Neuroscience*, *3*(1), 27–38.

Delgado, M. R., Nystrom, L. E., Fissell, C., Noll, D. C., & Fiez, J. A. (2000). Tracking the hemodynamic responses to reward and punishment in the striatum. *Journal of Neurophysiology*, *84*(6), 3072–3077. http://doi.org/10.1152/jn.2000.84.6.3072

Diener, E. (1984). Subjective well-being. *Psychological Bulletin*, *95*(3), 542–575.

Diener, E. (2000). Subjective well-being: The science of happiness and a proposal for a national index. *American Psychologist*, *55*(1), 34–43. http://doi.org/10.1037//0003-066X.55.1.34

Diener, E., Emmons, R., Larsen, R. J., & Griffin, S. (1985). The Satisfaction with Life scale. *Journal of Personality Assessmemt*, *49*(1), 71–75. http://doi.org/10.1207/s15327752jpa4901_13

Diener, E., Sandvik, E., & Pavot, W. (2009). Happiness is the frequency, not the intensity, of positive versus negative affect. In *Assessing well-being* (pp. 213–231). Dordrecht: Springer.

Diener, E., Suh, E. M., Lucas, R. E., & Smith, H. L. (1999). Subjective well-being: Three decades of progress. *Psychological Bulletin*, *125*(2), 276–302. http://doi.org/10.1037/0033-2909.125.2.276

Doré, B. P., Boccagno, C., Burr, D., Hubbard, A., Long, K., Weber, J., … Ochsner, K. N. (2017). Finding positive meaning in negative experiences engages ventral striatal and ventromedial prefrontal regions associated with reward valuation. *Journal of Cognitive Neuroscience*, *29*(2), 235–244. http://doi.org/https://doi.org/10.1162/jocn_a_01041

Ebner-Priemer, U. W., & Trull, T. J. (2009). Ecological momentary assessment of mood disorders and mood dysregulation. *Psychological Assessment*, *21*(4), 463–475. http://doi.org/10.1037/a0017075

Eckblad, M., & Chapman, L. J. (1986). Development and validation of a scale for hypomanic personality. *Journal of Abnormal Psychology*, *95*(3), 214.

Eid, M., & Diener, E. (1999). Intraindividual variability in affect: Relibility, validity and personality correlates. *Journal of Personality and Social Psychology*, *76*(4), 666–676.

Eldar, E., & Niv, Y. (2015). Interaction between emotional state and learning underlies mood instability. *Nature Communications*, *6*(1), 6149. http://doi.org/10.1038/ncomms7149

Eldar, E., Rutledge, R. B., Dolan, R. J., & Niv, Y. (2016). Mood as representation of momentum. *Trends in Cognitive Sciences*, *20*(1), 15–24. http://doi.org/10.1016/j.tics.2015.07.010

Engen, H. G., Kanske, P., & Singer, T. (2017). The neural component-process architecture of endogenously generated emotion. *Social Cognitive and Affective Neuroscience*, *12*(2), 197–211. http://doi.org/10.1093/scan/nsw108

Engen, H. G., & Singer, T. (2014). Compassion-based emotion regulation up-regulates experienced positive affect and associated neural networks. *Social Cognitive and Affective Neuroscience*, *10*(9), 1291–1301. http://doi.org/10.1093/scan/nsv008

Etkin, A., Büchel, C., & Gross, J. J. (2015). The neural bases of emotion regulation. *Nature Reviews Neuroscience*, *16*(11), 693–700. http://doi.org/10.1038/nrn4044

Eysenck, H. J., & Eysenck, M. W. (1987). *Personality and individual differences*. New York: Plenum.

Ferring, D., Filipp, S.-H., & Schmidt, K. (1996). Die "Skala zur Lebensbewertung": Empirische Skalenkonstruktion und erste Befunde zu Reliabilität, Stabilität und Validität. *Zeitschrift Für Differentielle Und Diagnostische Psychologie*, *17*(3), 141–153.

Fredrickson, B. L. (2001). The role of positive emotions in positive psychology: The broaden-and-build theory of positive emotions. *American Psychologist*, *56*(3), 218–226. http://doi.org/10.1037/0003-066X.56.3.218

Fredrickson, B. L., & Branigan, C. (2005). Positive emotions broaden the scope of attention and thought-action repertoires. *Cognition & Emotion*, *19*(3), 313–332. http://doi.org/10.1080/02699930441000238

Fredrickson, B. L., & Joiner, T. (2002). Positive emotions trigger upward spirals toward emotional well-being. *Psychological Science*, *13*(2), 172–175.

Fredrickson, B. L., & Levenson, R. W. (1998). Positive emotions speed recovery from the cardiovascular sequelae of negative emotions. *Cognition and Emotion*, *12*(2), 191–220. http://doi.org/10.1080/026999398379718

Gable, P. A., & Harmon-Jones, E. (2008). Approach-motivated positive affect reduces breadth of attention. *Psychological Science*, *19*(5), 476–482. http://doi.org/10.1111/j.1467-9280.2008.02112.x

Gable, S. L., Reis, H. T., Impett, E. A., & Asher, E. R. (2004). What do you do when things go right? The intrapersonal and interpersonal benefits of sharing positive events. *Journal of Personality and Social Psychology*, *87*(2), 228–245. http://doi.org/10.1037/0022-3514.87.2.228

Garland, E. L., Fredrickson, B. L., Kring, A. M., Johnson, D. P., Meyer, P. S., & Penn, D. L. (2010). Upward spirals of positive emotions counter downward spirals of negativity: Insights from the broaden-and-build theory. *Clinical Psychology Review*, *30*(7), 849–864. http://doi.org/10.1016/j.cpr.2010.03.002.Upward

Garnefski, N., Kraaij, V., & Spinhoven, P. (2001). Negative life events, cognitive emotion regulation and emotional problems. *Personality and Individual Differences*, *30*(8), 1311–1327. http://doi.org/10.1016/S0191-8869(00)00113-6

Gasper, K. (2018). Utilizing Neutral Affective States in Research: Theory, Assessment, and

Recommendations. *Emotion Review*, *10*(3), 255–266. http://doi.org/10.1177/1754073918765660

Gentzler, A. L., Morey, J. N., Palmer, C. A., & Yi, C. Y. (2013). Young adolescents' responses to positive events: Associations with positive affect and adjustment. *Journal of Early Adolescence*, *33*(5), 663–683. http://doi.org/10.1177/0272431612462629

Giuliani, N. R., McRae, K., & Gross, J. J. (2008). The up- and down-regulation of amusement: experiential, behavioral, and autonomic consequences. *Emotion*, *8*(5), 714–719. http://doi.org/10.1037/a0013236

Gorgolewski, K. J., Varoquaux, G., Rivera, G., Schwarz, Y., Ghosh, S. S., Maumet, C., … Margulies, D. S. (2015). NeuroVault.org: a web-based repository for collecting and sharing unthresholded statistical maps of the human brain. *Frontiers in Neuroinformatics*, *9*, 8. http://doi.org/10.3389/fninf.2015.00008

Graybiel, A. M. (2000). The basal ganglia. *Current Biology*, *10*(14), R509–R511.

Greening, S. G., Osuch, E. A., Williamson, P. C., & Mitchell, D. G. V. (2014). The neural correlates of regulating positive and negative emotions in medication-free major depression. *Social Cognitive and Affective Neuroscience*, *9*(5), 628–637. http://doi.org/10.1093/scan/nst027

Gross, J. J. (1998). The emerging field of emotion regulation: An integrative review. *Review of General Psychology*, *2*(3), 271–299. http://doi.org/10.1037/1089-2680.2.3.271

Gross, J. J. (2002). Emotion regulation: Affective, cognitive, and social consequences. *Psychophysiology*, *39*(3), S0048577201393198. http://doi.org/10.1017/S0048577201393198

Gross, J. J. (2015). The extended process model of emotion regulation: Elaborations, applications, and future directions. *Psychological Inquiry*, *26*(1), 130–137. http://doi.org/10.1080/1047840X.2015.989751

Gross, J. J., & Barrett, L. F. (2011). Emotion generation and emotion regulation: One or two depends on your point of view. *Emotion Review*, *3*(1), 8–16. http://doi.org/10.1177/1754073910380974

Gross, J. J., & John, O. P. (2003). Individual differences in two emotion regulation processes: implications for affect, relationships, and well-being. *Journal of Personality and Social Psychology*, *85*(2), 348–362. http://doi.org/10.1037/0022-3514.85.2.348

Gross, J. J., & Levenson, R. W. (1995). Emotion elicitation using films. *Cognition and Emotion*, *9*(1), 87–108. http://doi.org/10.1080/02699939508408966

Gross, J. J., Richards, J. M., & John, O. P. (2006). Emotion regulation in everyday life. *Emotion Regulation in Couples and Families: Pathways to Dysfunction and Health*, *2006*, 13–35.

Gross, J. J., Sutton, S. K., & Ketelaar, T. (1998). Relations between affect and personality: Support for the affect-level and affective-reactivity views. *Personality and Social Psychology Bulletin*, *24*(3), 279–288.

Gross, J. J., & Thompson, R. A. (2007). Emotion regulation: Conceptual foundations. In J. J. Gross (Ed.), *Handbook of emotion regulation*. New York: Guilford Press.

Grosse Rueschkamp, J. M., Kuppens, P., Riediger, M., Blanke, E. S., & Brose, A. (2018). Higher

well-being is related to reduced affective reactivity to positive events in daily life. *Emotion*. http://doi.org/10.1037/emo0000557

Gruber, J., Kogan, A., Quoidbach, J., & Mauss, I. B. (2013). Happiness is best kept stable: Positive emotion variability is associated with poorer psychological health. *Emotion*, *13*(1), 1–6. http://doi.org/10.1037/a0030262

Gyurak, A., Gross, J. J., & Etkin, A. (2011). Explicit and implicit emotion regulation: A dual-process framework. *Cognition & Emotion*, *25*(3), 400–412. http://doi.org/10.1080/02699931.2010.544160

Haber, S. N., & Knutson, B. (2010). The reward circuit: Linking primate anatomy and human imaging. *Neuropsychopharmacology*, *35*(1), 4–26. http://doi.org/10.1038/npp.2009.129

Hamann, S., & Canli, T. (2004). Individual differences in emotion processing. *Current Opinion in Neurobiology*, *14*(2), 233–238. http://doi.org/10.1016/j.conb.2004.03.010

Harker, L., & Keltner, D. (2001). Expressions of positive emotion in women's college yearbook pictures and their relationship to personality and life outcomes across adulthood. *Journal of Personality and Social Psychology*, *80*(1), 112–124. http://doi.org/10.1037//0022-3514.80.1.112

Heiy, J. E., & Cheavens, J. S. (2014). Back to basics: A naturalistic assessment of the experience and regulation of emotion. *Emotion*, *14*(5), 878–891. http://doi.org/10.1037/a0037231

Heller, A. S., Fox, A. S., Wing, E. K., McQuisition, K. M., Vack, N. J., & Davidson, R. J. (2015). The neurodynamics of affect in the laboratory predicts persistence of real-world emotional responses. *Journal of Neuroscience*, *35*(29), 10503–10509. http://doi.org/10.1523/JNEUROSCI.0569-15.2015

Heller, A. S., Johnstone, T., Shackman, A. J., Light, S. N., Peterson, M. J., Kolden, G. G., … Davidson, R. J. (2009). Reduced capacity to sustain positive emotion in major depression reflects diminished maintenance of fronto-striatal brain activation. *Proceedings of the National Academy of Sciences*, *106*(52), 22445–22450. http://doi.org/10.1073/pnas.0910651106

Hoeksma, J. B., Oosterlaan, J., & Schipper, E. M. (2004). Emotion regulation and the dynamics of feelings: A conceptual and methodological framework. *Child Development*, *75*(2), 354–360. http://doi.org/10.1111/j.1467-8624.2004.00677.x

Hollenstein, T., Lichtwarck-Aschoff, A., & Potworowski, G. (2013). A model of socioemotional flexibility at three time scales. *Emotion Review*, *5*(4), 397–405. http://doi.org/10.1177/1754073913484181

Hoppmann, C. A., & Riediger, M. (2009). Ambulatory assessment in lifespan psychology: An overview of current status and new trends. *European Psychologist*, *14*(2), 98–108. http://doi.org/10.1027/1016-9040.14.2.98

Houben, M., Van Den Noortgate, W., & Kuppens, P. (2015). The relation between short-term emotion dynamics and psychological well-being: A meta-analysis. *Psychological Bulletin*, *141*(4), 901–930. http://doi.org/10.1037/a0038822

Howell, R. T., & Rodzon, K. S. (2011). An exploration of personality–affect relations in daily life: Determining the support for the affect-level and affect-reactivity views. *Personality and Individual Differences*, *51*(7), 797–801. http://doi.org/10.1016/j.paid.2011.06.020

Howland, M., Armeli, S., Feinn, R., & Tennen, H. (2017). Daily emotional stress reactivity in emerging adulthood: temporal stability and its predictors. *Anxiety, Stress and Coping*, *30*(2), 121–132. http://doi.org/10.1080/10615806.2016.1228904

Ito, T. A., Larsen, J. T., Smith, N. K., & Cacioppo, J. T. (1998). Negative information weighs more heavily on the brain: The negativity bias in evaluative categorizations. *Journal of Personality and Social Psychology*, *75*(4), 887–900. http://doi.org/10.1037/0022-3514.75.4.887

Joormann, J., & Gotlib, I. H. (2010). Emotion regulation in depression: Relation to cognitive inhibition. *Cognition & Emotion*, *24*(2), 281–298. http://doi.org/10.1080/02699930903407948

Jose, P. E., Lim, B. T., & Bryant, F. B. (2012). Does savoring increase happiness? A daily diary study. *The Journal of Positive Psychology*, *7*(3), 176–187. http://doi.org/10.1080/17439760.2012.671345

Kahneman, D., Krueger, A. B., Schkade, D. A., Schwarz, N., & Stone, A. A. (2004). A survey method for characterizing daily life experience: The day reconstruction method. *Science*, *306*(5702), 1776–1780. http://doi.org/10.1126/science.1103572

Kappas, A. (2011). Emotion and regulation are one! *Emotion Review*, *3*(1), 17–25. http://doi.org/10.1177/1754073910380971

Kashdan, T. B., & Rottenberg, J. (2010). Psychological flexiblility as a fundamental aspect of health. *Clinical Psychology Review*, *30*(7), 865–878. http://doi.org/10.1016/j.cpr.2010.03.001

Keyes, C. L. M. (2002). The mental health continuum : From languishing to flourishing in life. *Journal of Health and Social Behaviour*, *43*(2), 207–222.

Kim, S. H., & Hamann, S. (2007). Neural correlates of positive and negative emotion regulation. *Journal of Cognitive Neuroscience*, *19*(5), 776–798. http://doi.org/10.1162/jocn.2007.19.5.776

Knutson, B., Fong, G. W., Adams, C. M., Varner, J. L., & Hommer, D. (2001). Dissociation of reward anticipation and outcome with event-related fMRI. *Neuroreport*, *12*(17), 3683–3687. http://doi.org/doi.org/10.1097/00001756-200112040-00016

Knutson, B., Fong, G. W., Bennett, S. M., Adams, C. M., & Hommer, D. (2003). A region of mesial prefrontal cortex tracks monetarily rewarding outcomes: Characterization with rapid event-related fMRI. *NeuroImage*, *18*(2), 263–272. http://doi.org/10.1016/S1053-8119(02)00057-5

Kober, H., Barrett, L. F., Joseph, J., Bliss-Moreau, E., Lindquist, K. A., & Wager, T. D. (2008). Functional grouping and cortical–subcortical interactions in emotion: A meta-analysis of neuroimaging studies. *NeuroImage*, *42*(2), 998–1031. http://doi.org/10.1016/j.neuroimage.2008.03.059

Kohn, N., Eickhoff, S. B., Scheller, M., Laird, A. R., Fox, P. T., Habel, U., … Antonio, S. (2014). Neural network of cognitive emotion regulation — An ALE metaanalysis and MACM analysis.

Neuroimage, *87*, 345–355. http://doi.org/10.1016/j.neuroimage.2013.11.001.Neural

Koole, S. (2009). The psychology of emotion regulation: An integrative review. *Cognition and Emotion*, *23*(1), 4–41. http://doi.org/10.1080/02699930802619031

Koval, P., Brose, A., Pe, M. L., Houben, M., Erbas, Y., Champagne, D., & Kuppens, P. (2015). Emotional inertia and external events: The roles of exposure, reactivity, and recovery. *Emotion*, *15*(5), 625–636. http://doi.org/10.1037/emo0000059

Koval, P., & Kuppens, P. (2012). Changing emotion dynamics: Individual differences in the effect of anticipatory social stress on emotional inertia. *Emotion*, *12*(2), 256–267. http://doi.org/10.1037/a0024756

Koval, P., Pe, M. L., Meers, K., & Kuppens, P. (2013). Affect dynamics in relation to depressive symptoms: Variable, unstable or inert? *Emotion*, *13*(6), 1132–1141. http://doi.org/10.1037/a0033579

Kragel, P. A., & LaBar, K. S. (2016). Decoding the nature of emotion in the brain. *Trends in Cognitive Sciences*, *20*(6), 444–455. http://doi.org/10.1016/j.tics.2016.03.011

Kramer, I., Simons, C. J. P., Wigman, J. T. W., Collip, D., Jacobs, N., Derom, C., … Wichers, M. (2014). Time-lagged moment-to-moment interplay between negative affect and paranoia: New insights in the affective pathway to psychosis. *Schizophrenia Bulletin*, *40*(2), 278–286. http://doi.org/10.1093/schbul/sbs194

Kringelbach, M. L., & Berridge, K. C. (2009). Towards a functional neuroanatomy of pleasure and happiness. *Trends in Cognitive Sciences*, *13*(11), 479–487. http://doi.org/10.1016/j.tics.2009.08.006

Kuppens, P. (2015). It's about time: A special section on affect dynamics. *Emotion Review*, *7*(4), 297–300. http://doi.org/10.1177/1754073915590947

Kuppens, P., Oravecz, Z., & Tuerlinckx, F. (2010). Feelings change: Accounting for individual differences in the temporal dynamics of affect. *Journal of Personality and Social Psychology*, *99*(6), 1042–1060. http://doi.org/10.1037/a0020962

Kuppens, P., Stouten, J., & Mesquita, B. (2009). Individual differences in emotion components and dynamics: Introduction to the Special Issue. *Cognition and Emotion*, *23*(7), 1249–1258. http://doi.org/10.1080/02699930902985605

Kuppens, P., & Verduyn, P. (2017). Emotion dynamics. *Current Opinion in Psychology*, *17*, 22–26. http://doi.org/10.1016/j.copsyc.2017.06.004

Lang, F. R., & Lüdtke, O. (2005). Der Big Five-Ansatz der Persönlichkeitsforschung: Instrumente und Vorgehen. In *Persönlichkeit: Eine vergessene Größe der empirischen Sozialforschung* (pp. 29–39). VS Verlag für Sozialwissenschaften.

Langston, C. A. (1994). Capitalizing on and coping with daily-life events: Expressive responses to positive events. *Journal of Personality and Social Psychology*, *67*(6), 1112–1125. http://doi.org/10.1037/0022-3514.67.6.1112

Larsen, R. J., & Diener, E. (1987). Affect intensity as an individual difference characteristic: A review. *Journal of Research in Personality*, *21*(1), 1–39. http://doi.org/10.1016/0092-6566(87)90023-7

Larsen, R. J., & Ketelaar, T. (1991). Personality and susceptibility to positive and negative emotional states. *Journal of Personality and Social Psychology*, *61*(1), 132–140. http://doi.org/10.1037//0022-3514.61.1.132

Lazarus, R. S. (1991). *Emotion and adaptation*. New York: Oxford University Press.

Li, F., Yin, S., Feng, P., Hu, N., Ding, C., & Chen, A. (2018). The cognitive up- and down-regulation of positive emotion: Evidence from behavior, electrophysiology, and neuroimaging. *Biological Psychology*, *136*(June), 57–66. http://doi.org/10.1016/j.biopsycho.2018.05.013

Lindquist, K. A., Satpute, A. B., Wager, T. D., Weber, J., & Barrett, L. F. (2016). The brain basis of positive and negative affect: Evidence from a meta-analysis of the human neuroimaging literature. *Cerebral Cortex*, *26*(5), 1910–1922. http://doi.org/10.1093/cercor/bhv001

Lindquist, K. A., Wager, T. D., Kober, H., Bliss-Moreau, E., & Barrett, L. F. (2012). The brain basis of emotion: A meta-analytic review. *Behavioral and Brain Sciences*, *35*(03), 121–143. http://doi.org/10.1017/S0140525X11000446

Liu, X., Hairston, J., Schrier, M., & Fan, J. (2011). Common and distinct networks underlying reward valence and processing stages: A meta-analysis of functional neuroimaging studies. *Neuroscience & Biobehavioral Reviews*, *35*(5), 1219–1236. http://doi.org/10.1016/j.neubiorev.2010.12.012.

Livingstone, K. M., & Srivastava, S. (2012). Up-regulating positive emotions in everyday life: Strategies, individual differences, and associations with positive emotion and well-being. *Journal of Research in Personality*, *46*(5), 504–516. http://doi.org/10.1016/j.jrp.2012.05.009

Lucas, R. E., Le, K., & Dyrenforth, P. S. (2008). Explaining the extraversion/positive affect relation: Sociability cannot account for extraverts' greater happiness. *Journal of Personality*, *76*(3), 385–414. http://doi.org/10.1111/j.1467-6494.2008.00490.x

Lyubomirsky, S. (2001). Why are some people happier than others? The role of cognitive and motivational processes in well-being. *American Psychologist*, *56*(3), 239–249. http://doi.org/10.1037//0003-066X.56.3.239

Lyubomirsky, S., King, L., & Diener, E. (2005). The benefits of frequent positive affect: Does happiness lead to success? *Psychological Bulletin*, *131*(6), 803–855. http://doi.org/10.1037/0033-2909.131.6.803

Mathôt, S., Schreij, D., & Theeuwes, J. (2012). OpenSesame: An open-source, graphical experiment builder for the social sciences. *Behavior Research Methods*, *44*(2), 314–324. http://doi.org/10.3758/s13428-011-0168-7

Mauss, I. B., Bunge, S. A., & Gross, J. J. (2007). Automatic emotion regulation. *Social and Personality Psychology Compass*, *1*(1), 146–167. http://doi.org/10.1111/j.1751-9004.2007.

00005.x

Mauss, I. B., Levenson, R. W., McCarter, L., Wilhelm, F. H., & Gross, J. J. (2005). The tie that binds? Coherence among emotion experience, behavior, and physiology. *Emotion*, *5*(2), 175–190. http://doi.org/10.1037/1528-3542.5.2.175

McConville, C., & Cooper, C. (1998). Personality correlates of variable moods. *Personality and Individual Differences*, *26*(1), 65–78. http://doi.org/10.1016/S0191-8869(98)00139-1

McRae, K., Jacobs, S. E., Ray, R. D., John, O. P., & Gross, J. J. (2012). Individual differences in reappraisal ability: Links to reappraisal frequency, well-being, and cognitive control. *Journal of Research in Personality*, *46*(1), 2–7. http://doi.org/10.1016/j.jrp.2011.10.003

McRae, K., & Mauss, I. B. (2016). Increasing positive emotion in negative contexts: Emotional consequences, neural correlates, and implications for resilience. *Positive Neuroscience*, 159–174.

McRae, K., Ochsner, K. N., Mauss, I. B., Gabrieli, J. J. D., & Gross, J. J. (2008). Gender differences in emotion regulation: An fMRI study of cognitive reappraisal. *Group Processes & Intergroup Relations*, *11*(2), 143–162. http://doi.org/10.1177/1368430207088035

Mihajlovic, V., Grundlehner, B., Vullers, R., & Penders, J. (2015). Wearable, wireless EEG solutions in daily life applications: What are we missing? *IEEE Journal of Biomedical and Health Informatics*, *19*(1), 6–21. http://doi.org/10.1109/JBHI.2014.2328317

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annu Rev Neurosci.*, *24*(1), 167–202. http://doi.org/10.1146/annurev.phyto.41.052002.095656

Mitchell, G. (2012). Revisiting truth or triviality: The external validity of research in the psychological laboratory. *Perspectives on Psychological Science*, *7*(2), 109–117. http://doi.org/10.1177/1745691611432343

Morawetz, C., Bode, S., Derntl, B., & Heekeren, H. R. (2017). The effect of strategies, goals and stimulus material on the neural mechanisms of emotion regulation: A meta-analysis of fMRI studies. *Neuroscience and Biobehavioral Reviews*, *72*(December), 111–128. http://doi.org/10.1016/j.neubiorev.2016.11.014

Morelli, S. A., Knutson, B., & Zaki, J. (2018). Neural sensitivity to personal and vicarious reward differentially relate to prosociality and well-being. *Social Cognitive and Affective Neuroscience*, *13*(8), 831–839.

Moutsiana, C., Fearon, P., Murray, L., Cooper, P., Goodyer, I., Johnstone, T., & Halligan, S. (2014). Making an effort to feel positive: Insecure attachment in infancy predicts the neural underpinnings of emotion regulation in adulthood. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *55*(9), 999–1008. http://doi.org/10.1111/jcpp.12198

Mund, M., & Neyer, F. J. (2014). Treating personality-relationship transactions with respect: Narrow facets, advanced models, and extended time frames. *Journal of Personality and Social Psychology*, *107*(2), 352–368. http://doi.org/10.1037/a0036719

Myers, D. G., & Diener, E. (1995). Who is happy? *Psychological Science*, *6*(1), 10–19.

Myin-Germeys, I., van Os, J., Schwartz, J. E., Stone, A. A., & Delespaul, P. A. (2001). Emotional reactivity to daily life stress in psychosis. *Archives of General Psychiatry*, *58*(12), 1137–1144.

Nelis, D., Quoidbach, J., Hansenne, M., & Mikolajczak, M. (2011). Measuring individual differences in emotion regulation: The emotion regulation profile-revised (ERP-R). *Psychologica Belgica*, *51*(1), 49. http://doi.org/10.5334/pb-51-1-49

Nesselroade, J. R. (1991). The warp and the woof of the developmental fabric. In R. M. Downs, L. S. Liben, & D. S. Palermo (Eds.), *Visions of aesthetics, the environment, and development: The legacy of Joachim F. Wohlwill* (pp. 213–240). Hillsdale, NJ: Lawrence Erlbaum Associates.

Nesselroade, J. R. (2001). Intraindividual variability in development within and between individuals. *European Psychologist*, *6*(3), 187.

Nezlek, J. B., & Plesko, R. M. (2003). Affect-and self-based models of relationships between daily events and daily well-being. *Personality and Social Psychology Bulletin*, *29*(5), 585–596. http://doi.org/10.1177/0146167203251533

O'Doherty, J. P., Deichmann, R., Critchley, H. D., & Dolan, R. J. (2002). Neural responses during anticipation of a primary taste reward. *Neuron*, *33*(5), 815–826. http://doi.org/10.1016/S0896-6273(02)00603-7

Ochsner, K. N., Bunge, S. A., Gross, J. J., & Gabrieli, J. D. E. (2002). Rethinking feelings: an FMRI study of the cognitive regulation of emotion. *Journal of Cognitive Neuroscience*, *14*(8), 1215–1229. http://doi.org/10.1162/089892902760807212

Ochsner, K. N., & Feldman Barrett, L. (2001). A multiprocess perspective on the neuroscience of emotion. In T. J. Mayne & G. A. Bonanno (Eds.), *Emotion: Current issues and future directions* (pp. 38–81). New York: Guilford.

Ochsner, K. N., & Gross, J. J. (2008). Insights from social cognitive and affective neuroscience. *Current Directions in Psychological Science*, *17*(2), 153–158. http://doi.org/10.1111/j.1467-8721.2008.00566.x

Ochsner, K. N., Silvers, J. A., & Buhle, J. T. (2012). Functional imaging studies of emotion regulation: A synthetic review and evolving model of the cognitive control of emotion. *Annals of the New York Academy of Sciences*, *1251*(1), E1–E24. http://doi.org/10.1111/j.1749-6632.2012.06751.x

Oishi, S., Diener, E., Choi, D.-W., Kim-Prieto, C., & Choi, I. (2007). The dynamics of daily events and well-being across cultures: When less is more. *Journal of Personality and Social Psychology*, *93*(4), 685–98. http://doi.org/10.1037/0022-3514.93.4.685

Ong, A. D., Bergeman, C. S., Bisconti, T. L., & Wallace, K. A. (2006). Psychological resilience, positive emotions, and successful adaptation to stress in later life. *Journal of Personality and Social Psychology*, *91*(4), 730–749. http://doi.org/10.1037/0022-3514.91.4.730

Ong, A. D., Horn, J. L., & Walsh, D. A. (2007). Stepping into the light: modeling the intraindividual dimensions of hedonic and eudaemonic well-being. In *Oxford handbook of methods in positive*

psychology (pp. 12–25).

Ong, A. D., Sin, N. L., & Ram, N. (2018). 25 distinguishing between enduring and fragile positive affect: Implications for health and well-being in midlife. *The Oxford Handbook of Integrative Health Science*, (January 2019), 343. http://doi.org/10.1093/oxfordhb/9780190676384.013.35

Panksepp, J. (2004). *Affective neuroscience: The foundations of human and animal emotions*. Oxford university press.

Parducci, A. (1968). The relativism of absolute judgments. *Scientific American*, *219*(6), 84–93.

Peeters, F., Nicolson, N. A., Berkhof, J., Delespaul, P., & deVries, M. (2003). Effects of daily events on mood states in major depressive disorder. *Journal of Abnormal Psychology*, *112*(2), 203–211. http://doi.org/10.1037/0021-843X.112.2.203

Phelps, E. A., & LeDoux, J. E. (2005). Contributions of the amygdala to emotion processing: From animal models to human behavior. *Neuron*, *48*(2), 175–187. http://doi.org/10.1016/j.neuron.2005.09.025

Piazza, J. R., Charles, S. T., Sliwinski, M. J., Mogle, J., & Almeida, D. M. (2013). Affective reactivity to daily stressors and long-term risk of reporting a chronic physical health condition. *Annals of Behavioral Medicine*, *45*(1), 110–120. http://doi.org/10.1007/s12160-012-9423-0

Power, J. D., Barnes, K. A., Snyder, A. Z., Schlaggar, B. L., & Petersen, S. E. (2012). Spurious but systematic correlations in functional connectivity MRI networks arise from subject motion. *Neuroimage*, *59*(3), 2142–2154.

Power, J. D., Schlaggar, B. L., & Petersen, S. E. (2015). Recent progress and outstanding issues in motion correction in resting state fMRI. *NeuroImage*, *105*, 536–551. http://doi.org/10.1016/j.neuroimage.2014.10.044

Quoidbach, J., Berry, E. V., Hansenne, M., & Mikolajczak, M. (2010). Positive emotion regulation and well-being: Comparing the impact of eight savoring and dampening strategies. *Personality and Individual Differences*, *49*(5), 368–373. http://doi.org/10.1016/j.paid.2010.03.048

Quoidbach, J., Mikolajczak, M., & Gross, J. J. (2015). Positive interventions: An emotion regulation perspective. *Psychological Bulletin*, *141*(3), 655–693. http://doi.org/10.1037/a0038648

Radloff, L. S. (1977). CES-D scale: A self-report depression scale for research in the general population. *Applied Psychological Measurement*, *1*(3), 385–401. http://doi.org/10.1177/014662167700100306

Riediger, M. (2018). Ambulatory assessment in survey research: The multi-method ambulatory assessment project. In M. Erlinghagen, K. Hank, & M. Kreyenfeld (Eds.), *Innovation und Wissenstransfer in der empirischen Sozial-und Verhaltensforschung: Festschrift für Gert G. Wagner* (pp. 85–100). Frankfurt, New York: Campus Verlag.

Riediger, M., Schmiedek, F., Wagner, G. G., Lindenberger, U., Riedinger, M., Schmiedek, F., … Lindenberger, U. (2009). Seeking pleasure and seeking pain: Differences in prohedonic and contra-hedonic motivation from adolescence to old age. *Psychological Science*, *20*(12), 1529–

1535. http://doi.org/10.1111/j.1467-9280.2009.02473.x

Robinson, M. D., & Clore, G. L. (2002a). Belief and feeling: Evidence for an accessibility model of emotional self-report. *Psychological Bulletin*, *128*(6), 934–960. http://doi.org/10.1037//0033-2909.128.6.934

Robinson, M. D., & Clore, G. L. (2002b). Episodic and semantic knowledge in emotional self-report: Evidence for two judgment processes. *Journal of Personality and Social Psychology*, *83*(1), 198–215. http://doi.org/10.1037//0022-3514.83.1.198

Röcke, C., & Brose, A. (2013). Intraindividual variability and stability of affect and well-being. *GeroPsych*, *26*(3), 185–199. http://doi.org/10.1024/1662-9647/a000094

Röcke, C., Li, S.-C., & Smith, J. (2009). Intraindividual variability in positive and negative affect over 45 days: Do older adults fluctuate less than young adults? *Psychology and Aging*, *24*(4), 863–878. http://doi.org/10.1037/a0016276

Rosenberg, E. L. (1998). Levels of analysis and the organization of affect. *Review of General Psychology*, *2*(3), 247–270. http://doi.org/10.1037/1089-2680.2.3.247

Rothkirch, M., Schmack, K., Deserno, L., Darmohray, D., & Sterzer, P. (2014). Attentional modulation of reward processing in the human brain. *Human Brain Mapping*, *35*(7), 3036–3051. http://doi.org/10.1002/hbm.22383

Rottenberg, J. (2005). Mood and emotion in major depression. *Current Directions in Psychological Science*, *14*(3), 167–170. http://doi.org/10.1111/j.0963-7214.2005.00354.x

Rush, J., Ong, A. D., Hofer, S., & Horn, J. L. (2017). Capturing the complexity and dynamics of positive human health. *The Oxford Handbook of Positive Psychology, 3rd Edition*, *1*(February 2019), 1–17. http://doi.org/10.1093/oxfordhb/9780199396511.013.7

Rusting, C. L., & Larsen, R. J. (1997). Extraversion, neuroticism, and susceptibility to positive and negative affect: A test of two theoretical models. *Personality and Individual Differences*, *22*(5), 607–612. http://doi.org/10.1016/S0191-8869(96)00246-2

Rutledge, R. B., Skandali, N., Dayan, P., & Dolan, R. J. (2014). A computational and neural model of momentary subjective well-being. *Proceedings of the National Academy of Sciences*, *111*(33), 201407535. http://doi.org/10.1073/pnas.1407535111

Ryan, R. M., & Deci, E. L. (2001). On happiness and human potentials: A review of research on hedonic and eudaimonic well-being. *Annual Review of Psychology*, *52*(1), 141–166. http://doi.org/10.1146/annurev.psych.52.1.141

Ryff, C. D., & Keyes, C. L. M. (1995). The structure of psychological well-being revisited. *Journal of Personality and Social Psychology*, *69*(4), 719–727. http://doi.org/10.1037/0022-3514.69.4.719

Sabatinelli, D., Bradley, M. M., Lang, P. J., Costa, V. D., & Versace, F. (2007). Pleasure rather than salience activates human nucleus accumbens and medial prefrontal cortex. *Journal of Neurophysiology*, *98*(3), 1374–1379. http://doi.org/10.1152/jn.00230.2007.

Salas, C. E., Radovic, D., & Turnbull, O. H. (2012). Inside-out: Comparing internally generated and

externally generated basic emotions. *Emotion*, *12*(3), 568–578. http://doi.org/10.1037/a0025811

Schaefer, A., Nils, F. F. F., Sanchez, X., & Philippot, P. (2010). Assessing the effectiveness of a large database of emotion-eliciting films: A new tool for emotion researchers. *Cognition & Emotion*, *24*(7), 1153–1172. http://doi.org/10.1080/02699930903274322

Schultz, W. (2000). Multiple reward signals in the brain. *Nature Reviews Neuroscience*, *1*(3), 199. http://doi.org/10.1038/35044563

Schultz, W., Dayan, P., & Montague, P. R. (1997). Neural substrate of prediction and reward. *Science*, *275*(5306), 1593–1599. http://doi.org/10.1126/science.275.5306.1593

Seidel, M., King, J. A., Ritschel, F., Boehm, I., Geisler, D., Bernardoni, F., … Ehrlich, S. (2018). The real-life costs of emotion regulation in anorexia nervosa: A combined ecological momentary assessment and fMRI study. *Translational Psychiatry*, *8*(1), 28. http://doi.org/10.1038/s41398-017-0004-7

Seligman, M., & Csikszentmihalyi, M. (2000). Positive psychology: An introduction. *American Psychologist*, *55*(1), 5–14. http://doi.org/10.1037/0003-066X.55.1.5

Sheldon, K. M., & Elliot, A. J. (1999). Goal striving, need satisfaction, and longitudinal well-being: The self-concordance model. *Journal of Personality and Social Psychology*. http://doi.org/10.1037/0022-3514.76.3.482

Sheppes, G., & Gross, J. J. (2011). Is timing everything? Temporal considerations in emotion regulation. *Personality and Social Psychology Review*, *15*(4), 319–331. http://doi.org/10.1177/1088868310395778

Shiota, M. N., Keltner, D., & John, O. P. (2006). Positive emotion dispositions differentially associated with Big Five personality and attachment style. *The Journal of Positive Psychology*, *1*(2), 61–71. http://doi.org/10.1080/17439760500510833

Silvers, J. A., Wager, T. D., Weber, J., & Ochsner, K. N. (2015). The neural bases of uninstructed negative emotion modulation. *Social Cognitive and Affective Neuroscience*, *10*(1), 10–18. http://doi.org/10.1093/scan/nsu016

Silvers, J. A., Weber, J., Wager, T. D., & Ochsner, K. N. (2015). Bad and worse: Neural systems underlying reappraisal of high-and low-intensity negative emotions. *Social Cognitive and Affective Neuroscience*, *10*(2), 172–179. http://doi.org/10.1093/scan/nsu043

Simmons, J. P., Nelson, L. D., & Simonsohn, U. (2011). False-positive psychology. *Psychological Science*, *22*(11), 1359–1366. http://doi.org/10.1177/0956797611417632

Sin, N. L., Graham-Engeland, J. E., Ong, A. D., & Almeida, D. M. (2015). Affective reactivity to daily stressors is associated with elevated inflammation. *Health Psychology*, *34*(12), 1154–1165. http://doi.org/10.1037/hea0000240

Sliwinski, M. J. (2008). Measurement-burst designs for social health research. *Social and Personality Psychology Compass*, *2*(1), 245–261. http://doi.org/10.1111/j.1751-9004.2007.00043.x

Sliwinski, M. J., Almeida, D. M., Smyth, J., & Stawski, R. S. (2009). Intraindividual change and

variability in daily stress processes: Findings from two measurement-burst diary studies. *Psychology and Aging*, *24*(4), 828–840. http://doi.org/10.1037/a0017925

Sloman, S. A. (1996). The empirical case for two systems of reasoning. *Psychological Bulletin*, *119*(1), 3–22. http://doi.org/10.1037/0033-2909.119.1.3

Smith, J. L., & Hollinger-Smith, L. (2015). Savoring, resilience, and psychological well-being in older adults. *Aging and Mental Health*, *19*(3), 192–200. http://doi.org/10.1080/13607863.2014.986647

Smith, R. H., Diener, E., & Wedell, D. H. (1989). Intrapersonal and social comparison determinants of happiness: A range-frequency analysis. *Journal of Personality and Social Psychology*, *56*(3), 317–325. http://doi.org/10.1037/0022-3514.56.3.317

Solomon, R. L. (1980). The opponent-process theory of acquired motivation: The costs of pleasure and the benefits of pain. *American Psychologist*, *35*(8), 691–712. http://doi.org/10.1037/0003-066X.35.8.691

Speer, M. E., Bhanji, J. P., & Delgado, M. R. (2014). Savoring the past: Positive memories evoke value representations in the striatum. *Neuron*, *84*(4), 847–856. http://doi.org/10.1016/j.neuron.2014.09.028

Spreng, R. N., Stevens, W. D., Chamberlain, J. P., Gilmore, A. W., & Schacter, D. L. (2010). Default network activity, coupled with the frontoparietal control network, supports goal-directed cognition. *NeuroImage*, *53*(1), 303–317. http://doi.org/10.1016/j.neuroimage.2010.06.016

Suls, J., & Martin, R. (2005). The daily life of the garden-variety neurotic: Reactivity, stressor exposure, mood spillover, and maladaptive coping. *Journal of Personality*, *73*(6), 1485–1510. http://doi.org/10.1111/j.1467-6494.2005.00356.x

Tamir, M. (2009). What do people want to feel and why? *Current Directions in Psychological Science*, *18*(2), 101–105. http://doi.org/10.1111/j.1467-8721.2009.01617.x

Taylor, S. E., & Brown, J. D. (1988). Illusion and well-being: A social psychological perspective on mental health. *Psychological Bulletin*, *103*(2), 193–210. http://doi.org/10.1037/0033-2909.103.2.193

Tellegen, A., Watson, D., & Clark, L. A. (1999). On the dimensional and hierarchical structure of affect. *Psychological Science*, *10*(4), 297–303. http://doi.org/10.1111/1467-9280.00157

Thompson, R. J., Mata, J., Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Gotlib, I. H. (2012). The everyday emotional experience of adults with major depressive disorder: Examining emotional instability, inertia, and reactivity. *Journal of Abnormal Psychology*, *121*(4), 819–829. http://doi.org/10.1037/a0027978

Tugade, M. M., & Fredrickson, B. L. (2007). Regulation of positive emotions: Emotion regulation strategies that promote resilience. *Journal of Happiness Studies*, *8*(3), 311–333. http://doi.org/10.1007/s10902-006-9015-4

Tzourio-Mazoyer, N., Landeau, B., Papathanassiou, D., Crivello, F., Etard, O., Delcroix, N., … Joliot, M. (2002). Automated anatomical labeling of activations in SPM using a macroscopic

anatomical parcellation of the MNI MRI single-subject brain. *Neuroimage*, *15*(1), 273–289.

Vanderhasselt, M.-A., Brose, A., Koster, E. H. W., & De Raedt, R. (2016). Co-variation between stressful events and rumination predicts depressive symptoms: An eighteen months prospective design in undergraduates. *Behaviour Research and Therapy*, *87*, 128–133. http://doi.org/10.1016/j.brat.2016.09.003

Vrtička, P., Andersson, F., Grandjean, D., Sander, D., & Vuilleumier, P. (2008). Individual Attachment Style Modulates Human Amygdala and Striatum Activation during Social Appraisal. *PLoS ONE*, *3*(8), e2868. http://doi.org/10.1371/journal.pone.0002868

Vrticka, P., Sander, D., & Vuilleumier, P. (2011). Effects of emotion regulation strategy on brain responses to the valence and social content of visual scenes. *Neuropsychologia*, *49*(5), 1067–1082. http://doi.org/10.1016/j.neuropsychologia.2011.02.020

Wager, T. D., Davidson, M. L., Hughes, B. L., Lindquist, M. A., & Ochsner, K. N. (2008). Prefrontal-subcortical pathways mediating successful emotion regulation. *Neuron*, *59*(6), 1037–1050. http://doi.org/10.1016/j.neuron.2008.09.006

Wager, T. D., Phan, K. L., Liberzon, I., & Taylor, S. F. (2003). Valence, gender, and lateralization of functional brain anatomy in emotion: A meta-analysis of findings from neuroimaging. *NeuroImage*, *19*(3), 513–531. http://doi.org/10.1016/S1053-8119(03)00078-8

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology*, *54*(6), 1063–1070. http://doi.org/10.1037/0022-3514.54.6.1063

Watson, D., & Tellegen, A. (1985). Toward a consensual structure of mood. *Psychological Bulletin*, *98*(2), 219–235. http://doi.org/10.1037/0033-2909.98.2.219

Waugh, C. E., Thompson, R. J., & Gotlib, I. H. (2011). Flexible emotional responsiveness in trait resilience. *Emotion*, *11*(5), 1059–1067. http://doi.org/10.1037/a0024889.A

Webb, T. L., Miles, E., & Sheeran, P. (2012). Dealing with feeling: A meta-analysis of the effectiveness of strategies derived from the process model of emotion regulation. *Psychological Bulletin*, *138*(4), 775–808. http://doi.org/10.1037/a0027600

Wessa, M., Kanske, P., Neumeister, P., Bode, K., Heissler, J., & Schönfelder, S. (2010). EmoPics: Subjektive und psychophysiologische Evaluation neuen Bildmaterials für die klinisch-bio-psychologische Forschung. *Zeitschrift Für Klinische Psychologie Und Psychotherapie*, *39*(Suppl. 1/11), 77.

Wessman, A. E., & Ricks, D. F. (1966). Mood and personality.

Wichers, M. (2014). The dynamic nature of depression: A new micro-level perspective of mental disorder that meets current challenges. *Psychological Medicine*, *44*(7), 1349–1360. http://doi.org/10.1017/S0033291713001979

Wilhelm, F. H., Pfaltz, M. C., & Grossman, P. (2006). Continuous electronic data capture of physiology, behavior and experience in real life: towards ecological momentary assessment of

emotion. *Interacting with Computers*, *18*(2), 171–186. http://doi.org/10.1016/j.intcom.2005.07.001

Williams, D. G. (1990). Effects of psychoticism, extraversion, and neuroticism in current mood: A statistical review of six studies. *Personality and Individual Differences*, *11*(6), 615–630. http://doi.org/10.1016/0191-8869(90)90045-S

Wilson, T. D., Aronson, E., & Carlsmith, K. (2010). The art of laboratory experimentation. In *Handbook of Social Psychology* (Vol. 1, pp. 51–81). Hoboken, NJ, USA: John Wiley & Sons, Inc. http://doi.org/10.1002/9780470561119.socpsy001002

World Health Organization. (1998). Info package: mastering depression in primary care, version2.2. *Copenhagen: WHO, Regional Office for Europe*.

World Health Organization. (2014). WHO, 2014. Basic-documents-48th-edition. Retrieved from http://apps.who.int/gb/bd/PDF/bd48/basic-documents-48th-edition-en.pdf#page=1

Wrzus, C., & Roberts, B. W. (2017). Processes of personality development in adulthood: The TESSERA framework. *Personality and Social Psychology Review*, *21*(3), 253–277. http://doi.org/10.1177/1088868316652279

Wu, C. C., Samanez-Larkin, G. R., Katovich, K., & Knutson, B. (2014). Affective traits link to reliable neural markers of incentive anticipation. *NeuroImage*, *84*, 279–289. http://doi.org/10.1016/j.neuroimage.2013.08.055

Yarkoni, T., Poldrack, R. A., Nichols, T. E., Van Essen, D. C., & Wager, T. D. (2011). Large-scale automated synthesis of human functional neuroimaging data. *Nature Methods*, *8*(8), 665–670. http://doi.org/10.1038/nmeth.1635

Zautra, A. J., Affleck, G. G., Tennen, H., Reich, J. W., & Davis, M. C. (2005). Dynamic approaches to emotions and stress in everyday life: bolger and zuckerman reloaded with positive as well as negative affects. *Journal of Personality*, *73*(6), 1511–1538. http://doi.org/10.1111/j.0022-3506.2005.00357.x

Zilverstand, A., Parvaz, M. A., & Goldstein, R. Z. (2017). Neuroimaging cognitive reappraisal in clinical populations to define neural targets for enhancing emotion regulation. A systematic review. *NeuroImage*, *151*, 105–116. http://doi.org/10.1016/j.neuroimage.2016.06.009